

RELAYS IN AUTOMATIC TELEPHONY

THEIR CONSTRUCTION, DESIGN, AND
ADJUSTMENT, TOGETHER WITH THE
THEORY OF IMPULSING AND THE
MEASUREMENT OF TIME LAGS

BY

R. W. PALMER, A.M.I.E.E

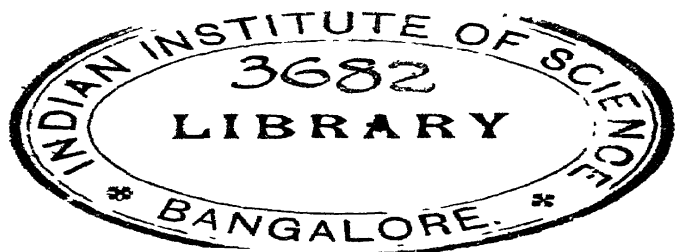
ASSISTANT ENGINEER, G.P.O. LONDON



LONDON

SIR ISAAC PITMAN & SONS, LTD.
PARKER STREET, KINGSWAY, W.C.2
BATH, MELBOURNE, TORONTO, NEW YORK

1930



PRINTED IN GREAT BRITAIN
AT THE PITMAN PRESS, BATH

PREFACE

JUDGING from the number of inquiries that I have received in the past, both from engineers and from students of Automatic Telephony, it would appear that the publication of some general information on relays is long overdue.

The object I have had in view in the preparation of this book has been to cover the syllabus of the City and Guilds Examination with respect to telephone relays, explaining as simply as possible how relays are constructed to meet the many diverse requirements in telephone practice and not forgetting the very difficult problem of impulsing. The subject of time lags has received considerable attention, as it is perhaps one of the most important in Automatic Telephony.

It will be observed that some unfamiliar terms have been used in the text, notably "uniselector" instead of R.L.S., and impulse "frequency" instead of impulse speed. These are terms laid down in a new publication of B.E.S.A., selections from which will be found in Appendix II.

Opinions expressed in the text are, of course, my personal opinions, but for assistance in collecting data, I have to thank many friends, both in the General Post Office and in the manufacturing firms, especially the A.T.M. Co. In addition I am indebted to the Institution of Post Office Electrical Engineers for allowing me to make extracts from their professional papers, but my thanks are directed particularly to the Engineer-in-Chief of the G.P.O., without whose valuable aid this and many other technical works on Telegraphy and Telephony would never have been published.

R. W. P.

LONDON, 1930.

CONTENTS

	PAGE
PREFACE	V
CHAPTER I	
RELAY CONSTRUCTION	1
General principles—Early manual types, torpedo, knife-edge, and multi-contact—Siemens auto type—R A T auto type— A.T.M. auto type	
CHAPTER II	
CONTACTS AND SPRINGS	20
Definitions—Circuit diagrams—Numbering of contacts— Make or break contacts—“X” contacts—“Y” contacts— Break-make contacts—Make-before-break contacts—Double- make contacts—Twin contacts—Buffers—Contact bounce— Contact materials—Spark quenches	
CHAPTER III	
MECHANICAL ADJUSTMENTS	39
Adjustment by tension gauge (Siemens)—Adjustment by thickness gauge (A.T.M.)—Gauging of break contacts—Gaug- ing of complete spring piles—Other gauging adjustments— Adjustment tools	
CHAPTER IV	
INDUCTIVE EFFECTS	52
Fast relays—Slow releasing relays—Slow operating relays— Sleeved relays—Ringing trip relays—Balanced windings— Nickel-iron relays	
CHAPTER V	
SPECIAL RELAYS	62
Two-step—Shunt-field—Polarized—Marginal—Pendulum—In- terlocking—Flat-type—Alternating current—Voice-frequency —Selector Magnets—Dashpot—Ratchet—Telegraph—Motor start—Moving coil—Thermostat	

CHAPTER VI

	PAGE
RELAY DESIGN	86
Magnetic circuit—Basic ampere-turns—Coil design—Adjustment charts—Saturate current—Hold current—Release current—Non-operate current—Operate current—Test and re-adjust values—Test points and guide resistance—Operating time—Pulse-operating time—Releasing time—Special conditions affecting relay functions	

CHAPTER VII

IMPULSING	112
Loop impulsing circuit—Dial condenser—Impulsing requirements—Impulsing relays—Loop variation—Leak variation—Effect of frequency on line variations—Effect of dial condenser on line variations—Effect of dial condenser on frequency variations—Target diagrams—Performance of selectors—Analysis of selector failures	

CHAPTER VIII

FURTHER IMPULSING CONSIDERATIONS	132
Effect of cable—of extension telephone—of transmission bridge—of voltage—of operate current adjustment—of residual adjustment—Impulse repetition—Compensating resistance—Battery impulsing—Reverted impulsing	

CHAPTER IX

TIME MEASURING INSTRUMENTS	144
Oscillograph—Other recording instruments—Electrical chronometers—Ballistic galvanometer methods—Electrostatic voltmeter method—Millisecond meter—Variable interrupter method—Condenser bridge method—Metroscope—Uniselector method—Milliammeter ratio tester—Disc ratio tester—Clockwork impulse frequency tester—Pendulum frequency tester	

APPENDIX I	177
Time lags of A.T.M. type relays and magnets in typical automatic telephone circuits	

APPENDIX II	181
British Standard Terms and Definitions relating to the text	

INDEX	186
-----------------	-----

RELAYS IN AUTOMATIC TELEPHONY

CHAPTER I

RELAY CONSTRUCTION

General Principles.

THE word relay in its general electrical sense has been applied to any apparatus which will repeat changes of current or potential. By far the most common relay is that which functions magnetically, but it is as well to bear in mind that the thermionic valve is also a relay, having the exclusive advantage of a zero time lag. Vacuum tubes and neon tubes are also used as relays, since one electrode can be used to start a discharge which will allow current to pass between other electrodes, again, it would be possible to construct an electrostatic relay on the principle of the electrostatic voltmeter and therefore consuming no power, but since these types of relay would be quite unsuitable for ordinary telephone switching circuits, they do not come within the scope of this book. The thermostat relay is frequently used, however, and is described in Chapter V.

Considering the electro-magnetic types, the first requirement is that there must be a coil of wire which will convert changes of current into changes of flux, secondly, there must be a magnetic circuit, part of which, the armature, is free to move by the laws of electro-dynamics and thus convert changes of flux into changes of position, and, thirdly, there must be electrical contacts actuated by the moving portion of the magnetic circuit in order to convert changes of position back into changes of current in some new circuit. Fig. 1 shows the path of flux in a hypothetical relay which fulfils these requirements but does not take into account

any of the constructional details. For the theory of the electro-magnet reference should be made to any textbook on electricity and magnetism. For telephone exchange work there are many special requirements, the chief of which is reliability, since as many as 200 relays may be used in setting up a single call in the director system; moreover, in a large exchange there may be as many as 120,000 relays, so that it will be appreciated that small dimensions and small cost are equally important considerations.

Early Manual Types.

Although described in order of development, these types of relays are still in use in many old manual exchanges, and

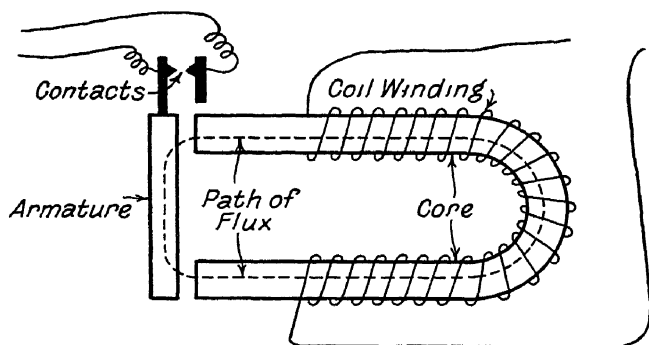


FIG. 1. THE RELAY PRINCIPLE

are superseded only when replacements are necessary or when circuit conditions demand the use of more modern types.

One of the earliest relays to be used commercially in telephone practice was the torpedo-type relay, which is shown in Fig. 2 (a). One pole of the electro-magnet is the central core round which the whole of the electrical winding is concentrated. The other pole is provided by the outer "shell," which is joined to the core by a circular iron mounting plate at the back or "heel" end. The armature is circular and the edge is bevelled, so that in the normal or "resting" position it falls away from the poles. It is prevented from

falling too far by the brass cap which fits over the end of the relay.

Electrical connection is made between a rigid silver contact in the centre of the armature (which is earthed via the mounting plate) and another silver contact on an insulated spring at the end of the central pole, this spring being connected by a short lead to a soldering tag at the heel end of the relay, alongside the tags belonging to the coil.

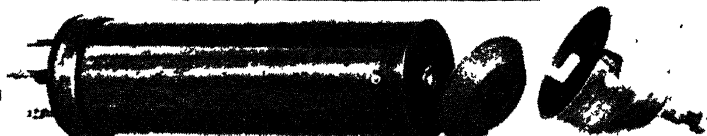
When current is supplied via the connecting tags to the exciting winding which surrounds the core, a flux is produced flowing round the magnetic circuit and across the air gap between the armature and the end of the core, and therefore, since the armature is free to move, subject to a small gravitational force, it will be attracted until it fits closely across the gap between core and shell, and the contacts will be closed. On the decay of flux resulting from the removal of the exciting current from the winding, the armature falls away again under the action of gravity alone, but the bevelled edge at the lowest point of the armature remains quite close to the shell; thus the subsequent movements of the armature may be likened to those of a hinge without any friction at the turning point.

Relays such as the torpedo-type just described are now superseded almost entirely, but they cannot be looked upon as being crude, as they contain many good points. For example, the reluctance of the magnetic circuit is quite low and the use of the iron shell provides mechanical protection for the winding, and also guards the magnetic circuit against interference by stray fluxes from adjacent relays or other apparatus. The electrical contacts have a good pressure between them. The range of movement of the armature (called the "stroke" or "travel") is adjustable by the turning of a screw which forms the back stop, and in this way the sensitivity of the relay as regards operate current may be varied; this is because the amount of flux generated for any given current depends on the shortness of the air gap between the armature and core, and also because the force of gravity, tending to prevent movement of the armature, is dependent on the angle at which the armature is leaning.

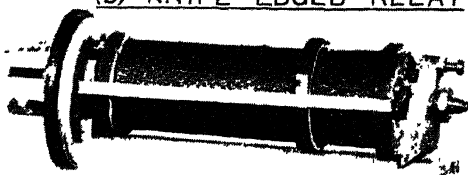
There are, however, several disadvantages, and some of these are overcome in the next type of relay, called the

"Knife-edged" relay This is shown in Fig. 2 (b). Here a greater winding space has been provided at the expense of the immunity from interference by stray fluxes provided by the "shell" type of magnetic circuit. The return circuit from the core to the armature is a bent piece of soft iron,

(a) TORPEDO-TYPE RELAY



(b) KNIFE-EDGED RELAY



(c) MULTI-CONTACT RELAY

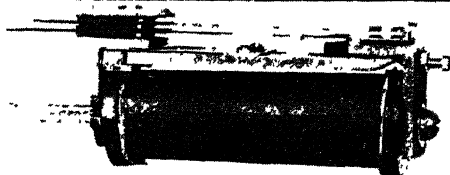


FIG 2. MANUAL TYPE RELAYS

forming a "yoke," and the armature is rectangular instead of round; it has a bevel only on the lower edge, which rests in a groove at the front end of the yoke. More important, however, is the placing of the contacts at the top edge of the armature instead of at the centre, because this provides a good clearance between the contacts with a shorter stroke than is possible with the torpedo type, and greater sensitivity as regards operate current can be obtained. Moreover,

it is now possible to examine the contacts when the relay is working, a maintenance facility not previously available

No reasonable criticism can be levelled at this "knife edge" relay from the point of view of magnetic efficiency, but improvement is still required in two respects. Firstly, a more flexible and more powerful control than gravity must be provided, and, secondly, the armature must be able to operate several pairs of electrical contacts simultaneously.

This is achieved in what are known as the "multi-contact" relays, an example of which is illustrated in Fig. 2 (c). In this case the part which was the armature is now fastened to the core to form a "pole piece," and that which was the yoke is now jointed at the rear or "heel-end" by means of a flexible spring to form an armature. The electrical contacts are separate from the armature assembly and are mounted at the ends of flat nickel-silver springs, which normally press the armature away from the pole piece. This material is almost as resilient as steel and yet is non-magnetic. The back stop consists of an adjustable stud whose head bears on the bevelled front edge of the armature, and which is screwed into the core. The contact springs are arranged in three "piles" or "packets" side by side, each connected to the armature by means of a short ebonite pip, yet the relay is kept in compact form, approximately 3 in. long.

The reluctance of the magnetic circuit of this multi-contact relay is, however, greater than that of the earlier relays because of the comparatively large air gap at the hinge end of the armature, and therefore the next step in the development of the relay was towards the elimination of air gaps, whilst still retaining the spring type of contacts. This is achieved by the "rocker" or "L shaped" armature, which is fitted over the end of a yoke in such a manner that it is pivoted at the angle of the "L," one arm forming the true "armature" and the other a lever for deflecting the contact springs. It is this general principle which has been used almost exclusively for automatic telephony, and more detailed descriptions of the various types are given below.

Siemens Auto Type.

This type of relay is manufactured not only by Messrs. Siemens Bros. & Co., Ltd., but also by Messrs. General Electric Co., Ltd. (formerly Peel Conner Telephone Works). It is shown in Figs. 3 and 4. Both yoke and armature are soft iron "pressings," a type of construction particularly suited to mass production, and all parts are thoroughly annealed after the machine work has been done. The front

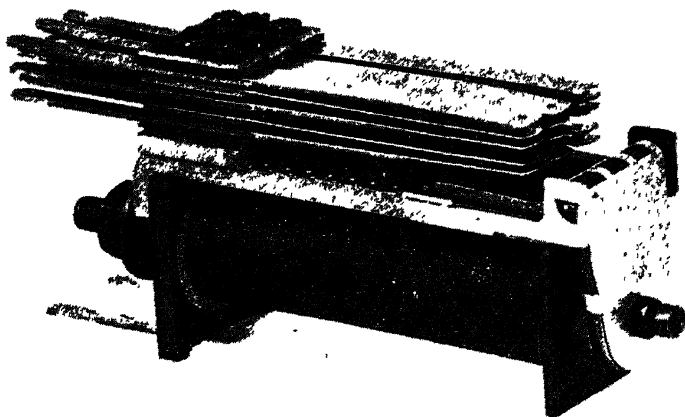


FIG 3. SIEMENS AUTO-TYPE RELAY

end of the yoke is shaped into a pronounced knife edge, over which the rocker armature is made to fit fairly closely by being shaped into a special V-bend. This reduces the reluctance of the magnetic circuit, and also provides a better mechanical fit, because the knife edge can be machined accurately and foreign matter is less liable to collect at the point of contact. If the relay is mounted vertically, i.e. with its springs uppermost, lateral displacement of the armature is prevented by a notch in the centre of the knife edge, engaging with a small pip on the inside of the V-bend in the armature; in addition, a stud, passing through a hole in the armature and screwed into the vertical face of the knife edge, prevents the armature from being

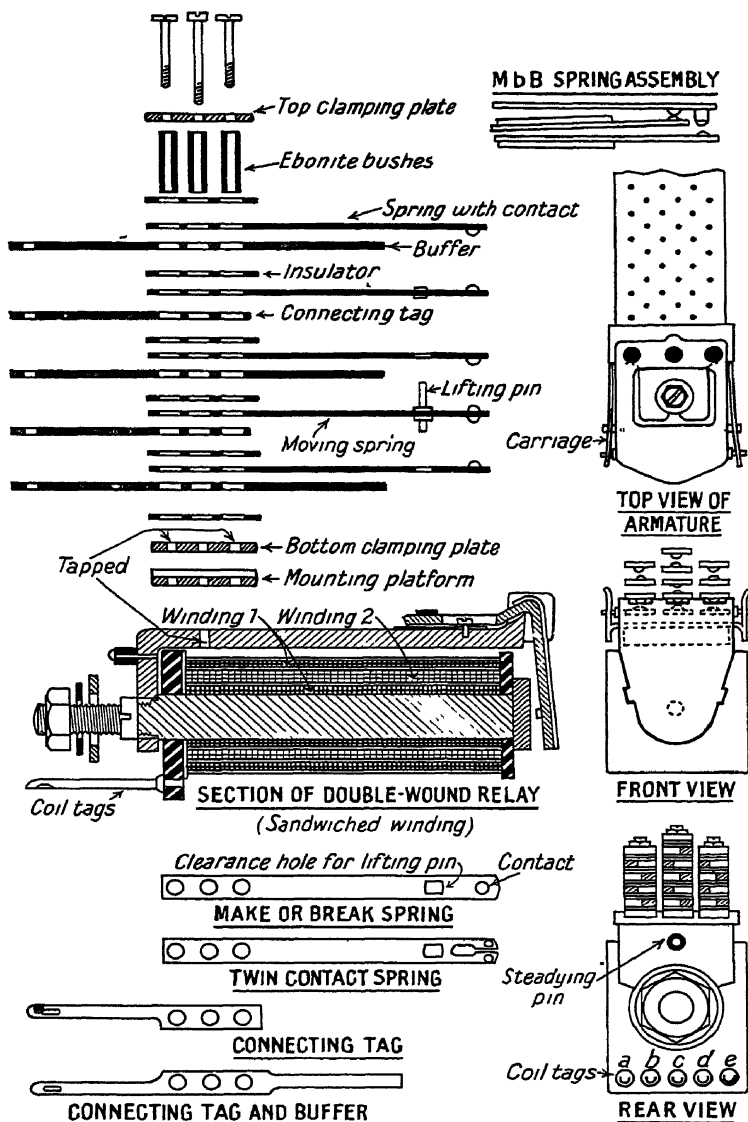


FIG. 4. SIEMENS AUTO-TYPE RELAY ASSEMBLY

displaced vertically. In automatic exchanges the relay is usually mounted on its side, and in such cases a carriage is provided on the yoke to prevent the armature from falling away from the knife edge. This carriage, made of nickel-silver, has side plates which form a loosely fitting hinge in conjunction with short brass pins riveted into the sides of the armature. The disposition of the parts, however, is such that the hinge does not interfere with the knife edge action under operating conditions. On the outer face of the armature is a thin aluminium plate on which can be stamped the manufacturer's code numbers, etc. For impulsing relays, and others where the introduction of additional air gaps is an advantage, the knife edge armature may be replaced by a "pin type" armature. (See page 118.)

The reason for mounting relays on their sides is that, in this position, the contact springs are vertical, thus $\left| \begin{smallmatrix} \times \\ \hline \end{smallmatrix} \right|$ instead of horizontal, thus $\overline{\times}$, and therefore dust is less liable to settle on the face of the contacts and produce faults.

The nickel-silver contact springs are parallel sided, and may be up to 18 in number, arranged in one to three interchangeable "piles" in such a manner that the load is distributed approximately equally, and each pile is held in position by three long screws. Two of these screws are threaded into the metal clamping plate at the base of the spring pile (but not into the yoke) so that the complete assembly of springs, insulators, etc., can be built up as a complete "pile" separate from the main portion of the relay; the spring assembly is attached to the relay by means of the centre screw, which passes freely through the pile and is screwed into the yoke. Rotational movement of the springs about this centre screw is prevented by a die-cast mounting platform with channels for the three piles.

The first "moving" spring in each pile is lifted directly by one of the three ebonite pins on the upper portion of the armature, a brass distance piece or "lifting pin" being provided if necessary. If there is a second spring set above this, the first moving spring is provided with a "lifting pin" projecting upwards as well as downwards, and after passing through clearance holes in any intermediate "make" or "break" spring, it bears on the underside of the second

moving spring; this second spring has an ebonite insulating pip where the brass pin touches. If there is a third moving spring, it is provided with a lifting pin, as before, projecting downwards to rest on the ebonite insulating pip in the second moving spring. There are exceptions to this arrangement, but the principle is not altered. If a specially heavy spring load is required, a thick phosphor-bronze bias spring may be included in the centre spring pile. The ratio of travel of contacts to travel of armature at the centre of the core is approximately 3.2, but the leverage of the armature itself, calculated from the point of contact between the armature lever and the lowest spring is 1.1.

The main object of the thick strips or "buffers" parallel with certain contact springs will be considered in the next chapter. These buffer strips are extended to the back of the relay, wherever possible, to form substantial soldering tags for the contacts. The insulation between adjacent springs is by means of bakelite washers, and that between springs and mounting screws is by means of ebonite sleeves.

The cylindrical core of soft iron on which the relay coil is wound is a forced fit in the heel piece of the yoke, in order to reduce air gaps at this point, also a circular brass nut is threaded on the core extension to hold the core rigidly in position. The air gap (or, more correctly speaking, the "non-magnetic gap") may not be eliminated entirely at this point owing to the non-magnetic surface finish which is used to protect the iron parts from rust. On the Siemens type of relay, the protective finish may be nickel plating subsequent to copper plating on the iron, or, alternatively, coslettizing, which is a chemical process producing a surface layer of phosphate of iron, giving a dull black finish. At the armature end of the core is an enlarged pole face, which is spot welded in position and is tin plated. It is found with this type of relay that the greatest sensitivity is obtained when the reluctance of the magnetic circuit in the unoperated position is exactly twice that in the operated position, and the particular diameter of the pole face chosen, $1\frac{1}{2}$ cm., fulfils this requirement in the majority of cases.

The "residual air gap" (commonly known as the "residual") is the gap between the armature and the pole face

when the relay is fully operated. It is needed to keep the reluctance of the magnetic circuit always above such a value that the residual magnetism in the iron will not retain the armature in the operated position when the current is cut off, or is reduced to a value at which the relay is required to release. It is controlled either by an adjustable brass "residual screw" with lock-nut, as shown in Fig. 3, or by phosphor-bronze pips or "stop pins" riveted on the inner face of the armature, as in Fig. 4. Fixed residuals of 20 or 12 mils are provided by a single pip, but if the gap required is as small as 4 mils, three residual pips are considered necessary to ensure that the core and armature do not touch inadvertently should their surfaces be out of alignment.

Mounting is effected by means of a nut on the projection of the heel end of the core, rotational movement being prevented by an additional short steadying pin, riveted to the heel piece. It is the general practice in this country to insulate all relay cores, etc., from the mounting rack which is connected to earth, the object being to prevent accidental earthing of the relay springs which may be connected to the main battery. In most cases circuits can be designed so that the contacts are in the earthed side of the circuit, or, if connection to battery is essential, a protective resistance of, say, 200 ohms may be inserted in the battery lead. However, this is not always possible, and, in any case, it does not avoid the connection of direct battery leads to relay coils, the tags of which may be exposed at the front if a heel end slug is fitted. On the other hand, in many automatic telephone equipments outside this country, the relays are deliberately earthed as a precaution against electrolytic corrosion of fine windings, due to leakage, particularly those windings connected to the positive pole of the battery (i.e. earthed). A compromise is used by Messrs. Siemens for their "Director" equipment where the relays are not insulated from the mounting plate, but the mounting plate with its relays is earthed through the relay cover only when the latter is in position.

When mounted on a selector or "relay set" plate, Siemens relays are usually in pairs with the contact springs on the outside; thus they form two vertical rows, which

are at $1\frac{3}{8}$ in. mounting centres horizontally, the relays being at approximately $1\frac{1}{8}$ in. centres in a vertical direction. The projection of the relay from the mounting plate is $3\frac{1}{4}$ in. Damage to the contact springs, when replacing the cover, is prevented by projections on the cover mounting.

The relay coil is wound directly on to the core with either enamelled or silk-covered wire, and the ends are brought out to soldering tags attached to the bakelite coil cheek at the heel end. A more detailed description of typical modern coil construction is given on page 18. The tags are from two to five in number, and in the new Post Office adjustment charts are designated *a*, *b*, *c*, *d*, *e*, from left to right in the rear view as shown. If a single winding is provided, only tags *a* and *e* are fitted. If there are two separate windings, the one nearest the core is usually connected to *a-b*, and the outside one to *d-e*. In certain cases where balanced circuits are required, a "sandwiched winding" is employed, as illustrated in Fig. 4, and in these cases *a-b* are the connections for the inner and outer windings in series, and *d-e* for the centre one. The central tag *c* is used only in special cases where a third winding is supplied, two of the windings being connected together with a single tag at the common point. In all cases the inner end of any winding is connected to the left-hand tag and is usually painted red, indicating that the earthed positive pole of the exchange battery should be connected to that side.

R.A.T. Auto Type.

These relays, manufactured by the Relay Automatic Telephone Co., Ltd., are illustrated in Fig. 5. The armature construction bears a great resemblance to the original manual type of L armature, the front end of the yoke being finished square instead of having a raised knife edge as in the Siemens type relay. The armature is kept in position by a screw fastened to the yoke and projecting through the armature, a special nut with a friction grip being fitted. The method of controlling the residual air gap is also unique and takes the form of a strip of brass $\frac{1}{4}$ in. wide and of the requisite thickness. This is fastened to the underside of the yoke and is bent so that it covers the face of the core.

A point of distinction between this and other types lies in the multiple contact assemblies, some examples of which are illustrated. The material used for the springs is phosphor-bronze. It will be noted that, with the normal size of yoke, there are only two spring piles side by side (instead of three in the Siemens type). This provides more room for the manipulation of adjusting tools, and if this spring capacity is insufficient the yoke may be extended into a platform on which as many as six separate spring piles may be mounted, the armature being correspondingly widened, as seen in Fig. 5. The platform space provided by this



FIG. 5. R.A.T. AUTO-TYPE RELAYS

wide yoke may also be used to carry other apparatus, e.g. supervisory lamps, small condensers, thermostat relays, resistance spools, etc., thus economizing space, which is such an important factor in telephone exchanges

The use of R.A.T. relays in Great Britain is now confined almost exclusively to private branch exchanges, and therefore is referred to somewhat briefly. The design and adjustment of this type of relay is not appreciably different from that of the Siemens type.

A.T.M. Auto Type.

This type of relay is the most commonly used in Great Britain for automatic telephony, and is, therefore, dealt with in greater detail. It was first manufactured in this country by Messrs. Automatic Telephone Manufacturing

Co., Ltd., and later by Messrs. Standard Telephones and Cables, Ltd. (late Western Electric), and also by Messrs. Ericsson, Ltd., but the construction of these latter models differs only slightly from the original A.T.M. type. The relays shown in Figs. 6 and 7 are those made by the A.T.M. Co.

It will be observed that, although there is no knife edge, the armature is magnetically of the L-shaped rocker type,

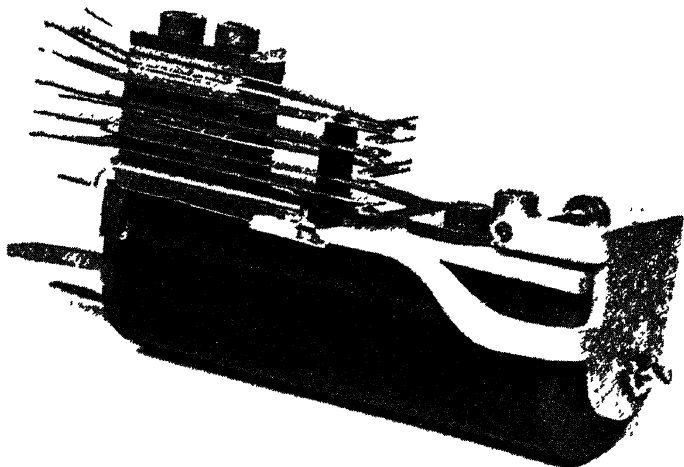


FIG. 6. A.T.M. AUTO-TYPE RELAY

but it is hinged on a phosphor-bronze pin to a non-magnetic bearing bracket screwed to the yoke. It is known as the "pin type" armature. The "hinge air gap" between the front end of the yoke and the inner face of the armature is adjusted by altering the position of the bearing bracket until there is only 1.5 mils clearance.

The nickel-silver contact springs, which are operated by a lever arm projecting from the side of the armature, are shaped so that they overhang the side of the yoke, and they also have projections at the heel end which form connecting tags, staggered to facilitate soldering. In this way

the overall "height" of the relay is reduced to a minimum, since it is not necessary to leave any gap for the armature between the lowest contact spring and the yoke

It will be seen from the plans of typical springs in Fig. 7 that, although the moving springs overhang the yoke throughout their length, the make and break springs overhang at their tips only, and therefore it is possible to couple all the moving springs together by means of ebonite collets without fouling the remainder. These collets, mounted in a direct line with the thrust of the armature lever, are fastened to one spring with a hollow brass rivet to prevent accidental displacement. The armature lever also has an ebonite bead to insulate it from the springs. Since the armature lever overhangs the yoke, a separate back stop is required, this being provided by a stamping which is fastened at the base of the contact spring assembly. The maximum number of spring piles is two, in which case an armature with two levers is used, but whenever possible the spring assembly is concentrated in one spring pile to facilitate adjustments, the second lever on the armature being omitted.

The method of insulating the springs eliminates the need for separate insulation of the holding screws. Each insulator is stamped out of sheet bakelite, and two circular "bosses" are formed by stamping half way through the material. This construction will be obvious from an inspection of Fig. 7. The springs fit over these bosses and are thereby prevented from touching the holding screws. If the thickness of the spring is less than that of the projecting boss, then the boss is automatically pressed back into the body of the insulator when the spring pile is tightened up. After assembly, the spring piles are clamped in a vice and then heated to drive any moisture out of the insulators. A further tightening is given while hot.

The position of the pin or hinge in relation to the rest of the armature determines the leverage, i.e. the ratio of travel of the springs (measured at the contacts) to the travel of the armature (measured at the centre of the core). There are two types of armature in use, No. 3 giving a ratio of 3 to 1, and No. 2 giving a ratio of 2 to 1, the latter being used on slow releasing relays because the reduced

leverage assists the armature to withstand the pressure of the springs during release.

In all cases, an adjustable brass residual screw with lock-nut is provided to control the "residual air gap" between

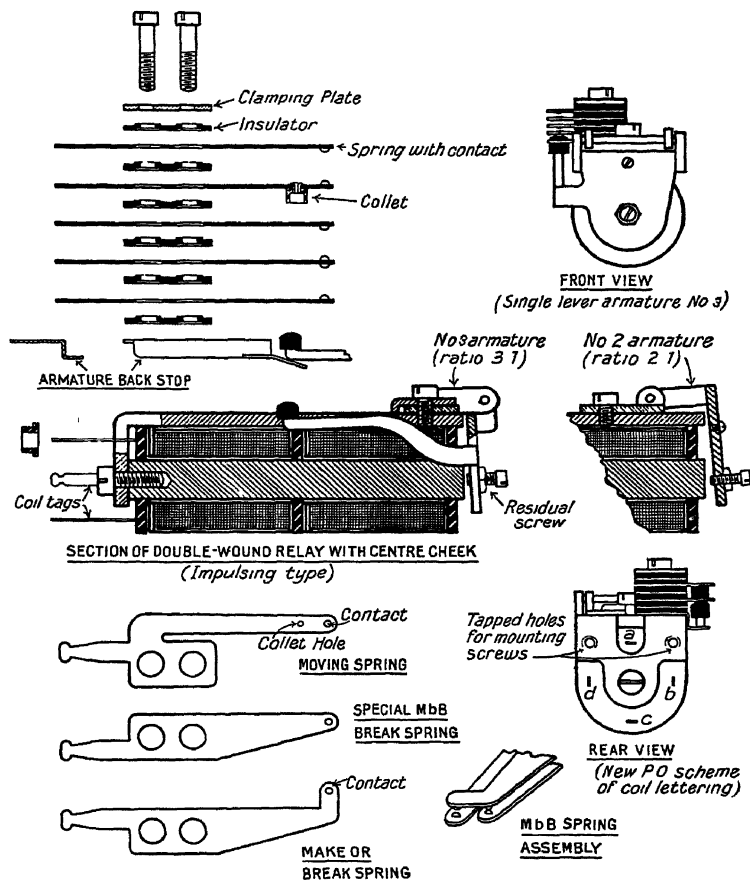


FIG. 7. A.T.M. AUTO-TYPE RELAY ASSEMBLY

armature and core face when the relay is operated. The heel end of the core butts against the heel piece of the yoke, and is held in position by an iron screw, which is threaded

into the core itself. Thus there is a small "heel air gap" represented by the thickness of the zinc plating which is used for protection against rust. The deposition of zinc, a common practice for this type of relay, may be electrolytic, or it may be produced by "sherardizing," a process which involves the heating of the iron parts while surrounded by zinc dust. An alternative is nickel plating, as on the Siemens type relay. The material used for the core is Swedish soft iron, but the yoke and armature are of cold rolled steel, pressed into shape and annealed subsequently to drilling, machining, etc. This is typical of modern relay practice, but the qualities of the materials used are different for the various manufacturers. On the face of the armature there may be a small aluminium name plate to show the code numbers of the relay, or, alternatively, the numbers may be painted on the underside of the yoke.

Mounting is achieved by screws inserted from the back of the mounting into tapped holes in the heel piece, but the relay as a whole is insulated from the frame or mounting plate by insulating washers and a sheet of bakelite between the mounting plate and the heel piece. The advantage of insulation is the prevention of trouble by accidental short circuits between "live" tags and the frame, this being specially important in certain double coil relays with heel end slugs, where one winding has intermediate tags at the front end of the spool (see page 10)

In all cases A.T.M. type relays are mounted on their sides, so that dust shall not settle on the face of the springs or contacts. In the case of selectors and rack-mounted relay sets (Fig. 8) there is a standard method of mounting which is important, because it affects the ultimate capacity of the spring piles. The relays are mounted in pairs side by side at $1\frac{1}{3}\frac{1}{2}$ in. mounting centres, and the mounting plates may accommodate up to 22 relays, one pair at $1\frac{1}{4}$ in. centres above the other; relays with double-lever armatures make an exception and require $\frac{1}{2}$ in. more space vertically. The projection of the relays from the mounting plate is $3\frac{1}{2}$ in. In all cases the springs are on the outer side of the plate in order to facilitate adjustment. Where "single armatures" are used (i.e. armatures with one lever and, therefore, one spring pile), the pile is on the

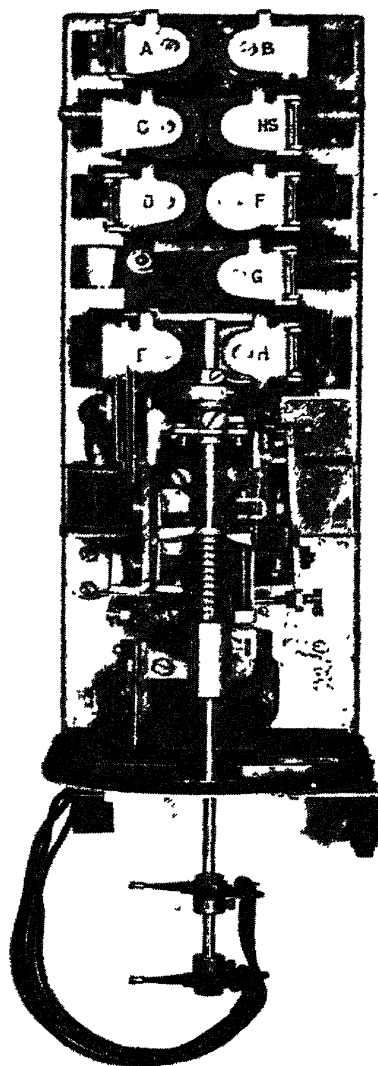


FIG. 8. MOUNTING OF RELAYS ON A SELECTOR
(P.B.X. Final, 2-10 lines)

upper side of the yoke. Thus, a relay to be mounted on the left-hand side of the mounting plate (looking from the front) will be assembled differently from one on the right-hand side, although they may have identical coils and spring capacities: they are identified by a prefix, *HL* or *HR* respectively, in the code number of the relay. Double armature relays, i.e. relays with two spring piles will be the same for either side, and therefore their code numbers are prefixed by *HLR*. In order that at least 50 per cent of the relays on a mounting plate may have a large spring assembly, the pairs of relays are mounted eccentrically on the plate (see Fig. 8), the result being that the maximum number of springs on a left-hand relay is generally 11 per spring pile, and on a right-hand relay 14 per spring pile, or 22 and 28 springs respectively for double-arm relays; the number is less if thick springs are used. Some of the relays are provided with "guide posts," short posts screwed to the top of the yoke to prevent the cover from fouling the contact springs when the cover is being replaced.

The "coils" or "spools" are wound directly on to the core between cheeks of red fibre, two turns of empire cloth being used as insulation between winding and core, and also, in the case of two coils concentrically wound, between the two layers of wire. A further layer of empire cloth is added to the outside as a protection against mechanical damage. The wire used is enamelled, but where windings with non-inductive resistance are incorporated, either for shunting the main coil or, perhaps, for some other independent function in the circuit in which it is used, the high resistance wire (e.g. Platinoid or Eureka) is usually insulated with a single silk covering. These non-inductive windings are placed on the relay core merely for convenience of housing. They are bifilar, that is to say, the wire is looped and the resulting double wire is wound on, "looped end" first, finishing up with the two free ends which form the terminals of the winding. In this way the inductive effect of one half of the wire from tag to loop is counter-balanced by that of the other half from loop to tag. The above particulars of coil construction apply to almost all modern types of telephone relay.

The coil tags on the A.T.M. type relay are four in number

and are placed symmetrically round the rear coil cheek. In the G.P.O. new standard adjustment charts are about to be introduced; they are lettered *a, b, c, d*, in a clockwise direction as viewed from the rear, counting *a* as the tag nearest the yoke. This is shown in Fig. 13. If there is but one winding, then the two tags *b* and *d* only are fitted, tag *b* being the inner end of the coil. If two windings are incorporated (this is the maximum on this type of relay), then the four tags are used, the inner winding being connected to *b-d*, and the outer to *a-c*, the first tag in each case being the inner end. On impulsing relays and other relays with balanced windings two coils are wound side by side, with a centre cheek between them instead of being one winding over another, and in this case the coil at the armature end is connected to *b-d*.

The above lettering does not apply to some of the older adjustment charts still in use, and therefore the old scheme that was used is given here for reference. The windings were terminated on exactly the same tags, but the lettering of these tags was as follows: On a single coil relay the two tags which are now *b* and *d* were then lettered *a* and *b*. On a double-wound relay the lettering was *a c b d* in a clockwise direction, instead of *a b c d*, so that the two windings were connected to *a-b* and *c-d* respectively.

CHAPTER II

CONTACTS AND SPRINGS

Definitions.

It is first necessary to define certain general terms used in connection with spring assemblies—

The “moving” spring or contact (sometimes called the “travelling” contact or “armature” spring) is that which is operated directly by the movement of the armature.

The “make” spring or contact (sometimes called the “front” contact) is that with which the moving spring makes contact, either directly or indirectly, when the armature is operated.

The “break” spring or contact (sometimes called the “back” contact) is that which is normally touching some other spring, but is separated from it, either directly or indirectly, by the operation of the moving spring

The word “contact” is, unfortunately, an ambiguous term, and may mean either a single piece of contact material or a spring containing a contact, or it may be used as an abbreviation for “contact assembly,” e.g. a “make contact,” meaning a pair of springs which make electrical connection when the relay is operated. The correct interpretation, however, is usually gathered from the context.

Circuit Diagrams.

The conventional methods of representing relays on circuit diagrams are numerous, but that adopted by the British Post Office for schematic diagrams, and followed by the majority of English manufacturers, is shown in Figs. 9, 23, and 40. The various types of relay coils which are represented there are described later in detail. The lay-out of circuits containing relays may be on one of three main principles, i.e. associated contacts, semi-detached contacts, or detached contacts. These are illustrated in Figs 10, 11, and 12, which show the circuit of the same final selector drawn in the three schemes for comparison.

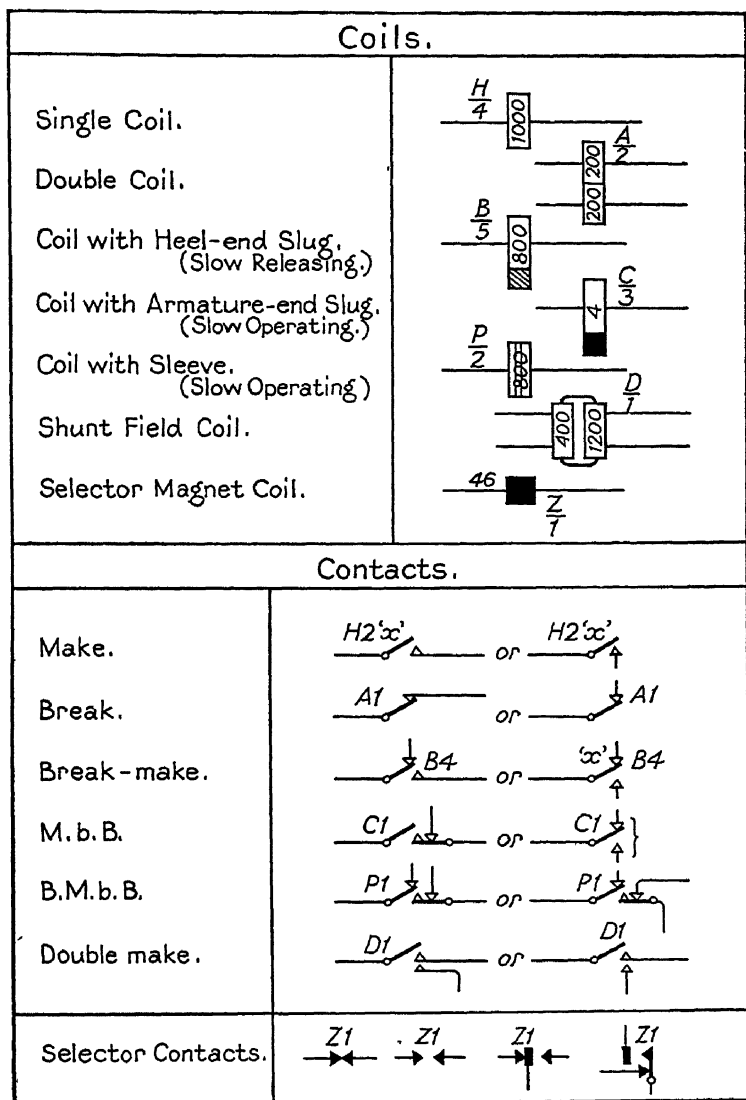


FIG. 9. CONVENTIONAL REPRESENTATION OF RELAYS AND MAGNETS

22

Jack springs make when switch is removed,

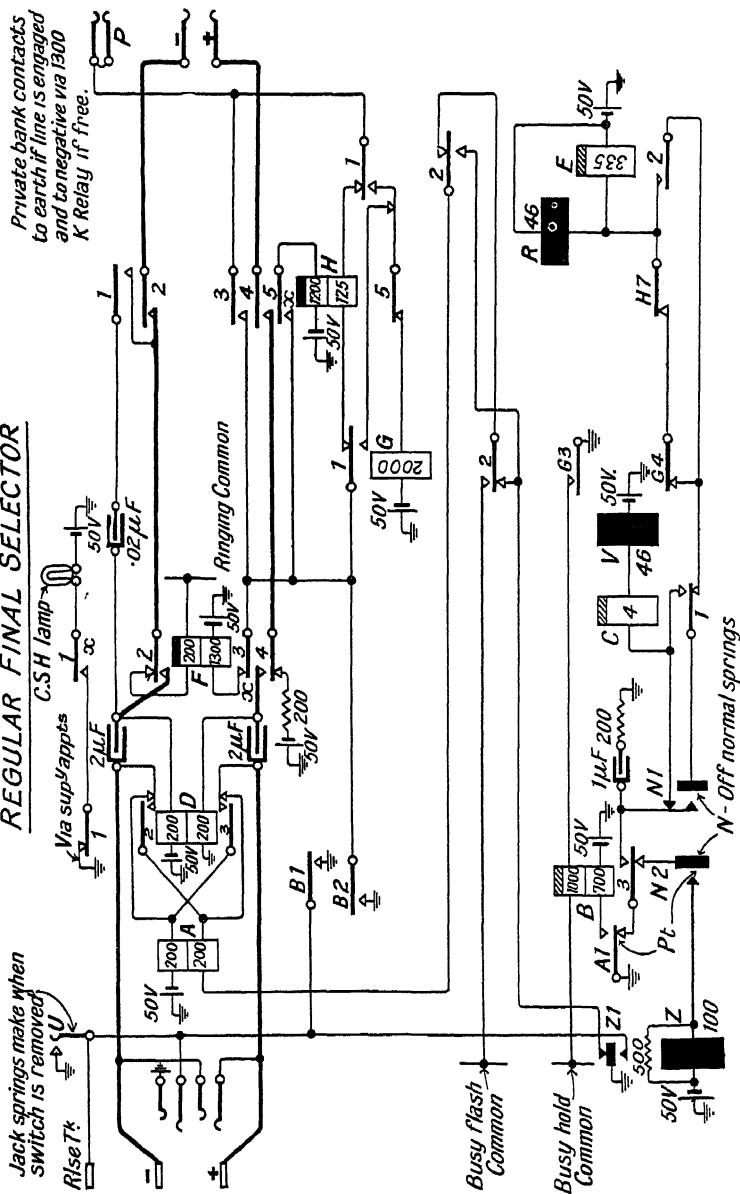


FIG 11. SEMI-DETACHED CONTACT DIAGRAM

REGULAR FINAL SELECTOR

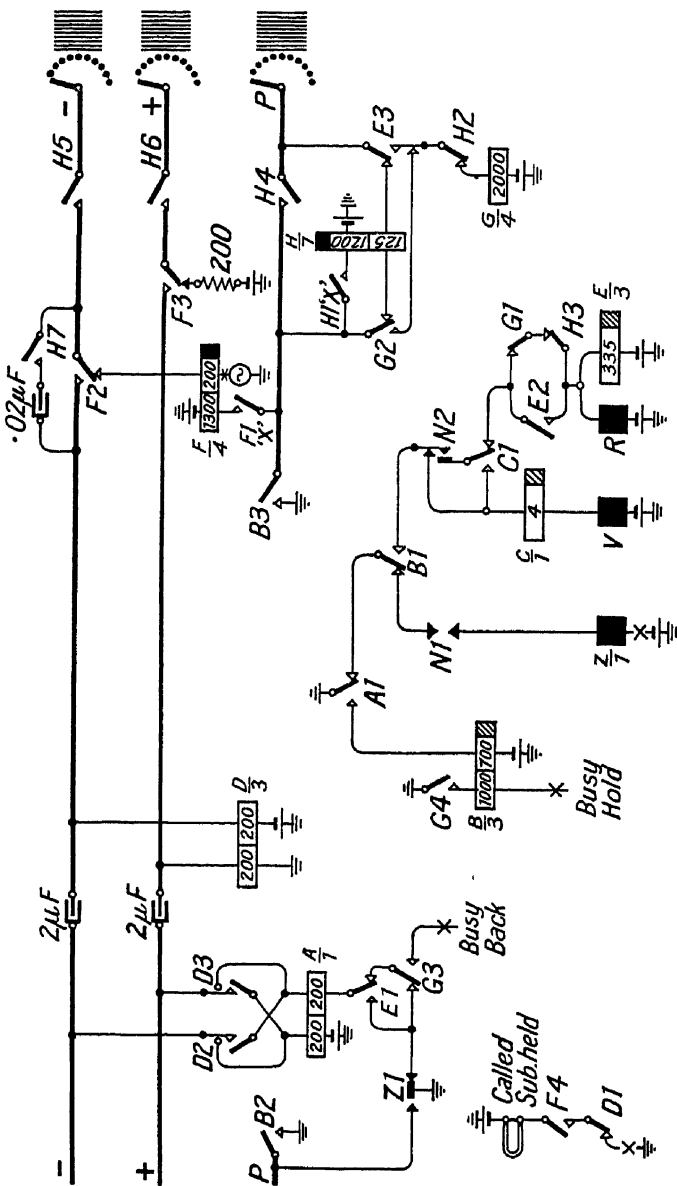


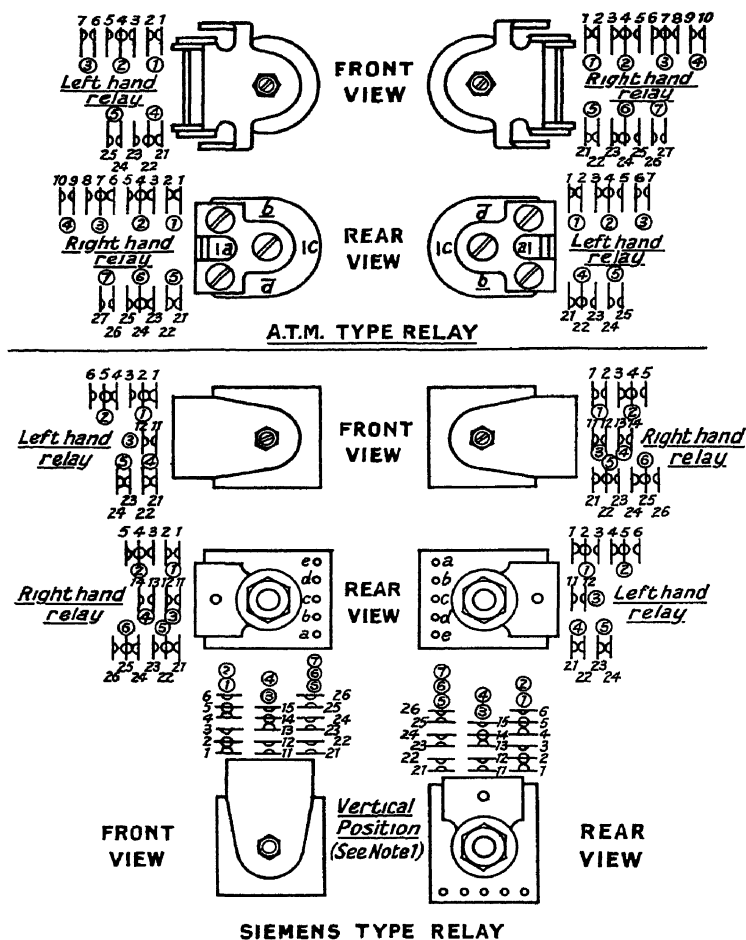
FIG. 12. DETACHED CONTACT DIAGRAM

In the associated contact scheme, all the relay coils and associated contacts are arranged as nearly as possible in the positions occupied in the switch, and therefore there is little scope for laying out the diagram to show the functions of the various parts of the apparatus.

There is an improvement in this respect in the semi-detached system, where the relay coils may be situated anywhere in the diagram so long as the contacts are in line with the coil, thus, an imaginary line drawn through the centre of the coil of a relay passes through all the contacts of that relay. There is no limit to the distance between contacts and coil, and the contacts are numbered consecutively irrespective of their positions on the relay.

The simplest kind of circuit diagram is the detached contact scheme, where coils and contacts are placed anywhere that is convenient for the lay-out of the circuit. Thus it is possible to see at a glance the operating paths for any particular part of the apparatus, and the possibility of error in tracing wires along an intricate route with bends and crosses and kinks is avoided. In other words, the circuit diagram has become an orderly arrangement of "routes" instead of a mass of wires. This scheme is essential for the understanding of circuits such as those of routiners, containing 50 or more relays with different functions, an example of a director routiner being shown in the frontispiece. Owing to the simplification, a smaller diagram may be produced, the original of this director routiner diagram being reduced from $13\frac{1}{2}$ ft. \times $2\frac{1}{2}$ ft. (associated contacts) to 3 ft. \times 2 ft. (detached contacts). It may be thought that some difficulty might be found in finding the contacts of a particular relay, but this is catered for by indicating against each coil the number of contact assemblies associated with it. For example, letter *H* over a 6 indicates that the *H* relay has six contact assemblies, and they will be found with very little difficulty, numbered *H*1, *H*2, etc., up to *H*6, there is, therefore, no possibility of a contact becoming overlooked.

Although the detached contact drawing is the only one which can be used satisfactorily for fault finding or instructional work, the associated contact system is still indispensable when it is required to know the exact connections



[FIG. 13. NUMBERING OF SPRINGS AND LETTERING OF COIL TAGS

Notes on Siemens Type Relays.

1. In this position a right-hand relay is used.
2. If centre spring packet is omitted, i.e. 2 spring packets only, the numbering of springs is 1, 2, 3, etc., and 21, 22, 23, etc., but the method of numbering the contact assemblies is unaltered.
3. If one spring set only, i.e. in centre, the spring numbering is 11, 12, 13, etc.

of the wires on the apparatus, e.g. during manufacture or repair, because in the other two systems an imaginary tee joint may be shown in place of a looped connection merely to simplify the arrangement of the diagram. For this reason it is usual to issue circuit diagrams in both systems, the detached contact scheme being called the "Schematic" diagram, and the semi-detached or associated contact scheme the "Wiring Diagram."

In some circuits the "wires" in the wiring diagram are omitted, and against each tag are entered the code letters and numbers of the tag or tags to which wires are connected.

Numbering of Contacts.

For the relay contacts there are two distinct schemes of numbering, (a) numbering of the individual contact springs with regard to their position on the relay for purposes of wiring diagrams and adjustment charts, and (b) numbering of the contact assemblies in direct sequence for use on schematic diagrams. In Fig. 13 the numbers of the contact *assemblies* are distinguished by being shown in circles. The diagram is self-explanatory, but it should be noted particularly that, whereas the number given to the last assembly is an indication of the total number of assemblies on the relay, the number given to the last spring is merely an indication of the number of springs in the last spring pile and not in the relay as a whole, thus, on the A.T.M. relay in the top left-hand corner of the diagram, the fact that there is a spring number 25 must not be taken to mean that there are 25 springs on the relay, but merely that No. 25 spring is in the lower spring pile (indicated by the "2" in the number), and that it is the fifth spring from the bottom (indicated by the "5")

Make or Break Contacts (abbr. "M" or "B").

The general construction of simple make or break contacts will be apparent from the general description of the modern auto-type relays. Spring thicknesses and the use of buffers are dealt with later in the chapter.

"X" Contacts.

If one or more contacts are operated earlier in the stroke

than the others, they are usually placed at the bottom of the spring pile and are designated x makes or x breaks, the letter x being shown against the contact on the circuit drawing and on the relay adjustment chart. The armature is made to operate these contacts before the other moving springs are disturbed at all. This applies only to cases where the advance operation is essential in the circuit, and not where the order of operation is inherent in the method of adjustment. (See page 43)

An important use of the x contact is in the two-step relay (page 62), but there are other more common examples. If a relay is required to operate and lock on the receipt of a short pulse of current, an x make contact may be used to connect up the locking circuit at the earliest possible moment; similarly, if the resistance in the operating circuit is too great to operate the relay fully, an x contact may be used to connect up an auxiliary circuit from the local battery

If, in these cases, it is not desirable to interfere with the current conditions in the operating circuit, a double wound relay may be used, one winding being used as a "line" coil and the other as a "locking" coil connected to the local battery via the x contact. With such an arrangement, it would appear that a break contact in the main spring assembly could be used to disconnect the line coil, since that coil would have completed its function as soon as the x contacts had closed. This self-interrupting of the line coil should be avoided, however, as the relay is liable to be released by the transformer effects in the locking coil when the line coil is disconnected. Once the relay has operated fully, of course, there is no objection to the circuit of the line coil being broken.

Another interpretation of the x contact is included in the following paragraph.

"Y" Contacts.

This term is applied to contacts which are required to function later than others by virtue of the circuit operation. Frequently an x and y contact are specified on the same relay, and in this case the interpretation is that the x contact must operate before the y . It is achieved by

the relative adjustments of the resting positions of the particular make or break springs.

A more definite sequence may be obtained by coupling the make spring of the x contact to the moving spring of the y contact, so that the force required for the operation of the y spring assembly is actually transmitted via the x contacts when they are closed. Thus, there is no possibility of the contacts operating in the wrong order, whatever the adjustments may be.

Break-make Contacts (abbr. "BM").

In this assembly of contacts, the moving spring can make connection with either a break or a make contact, and, therefore, the moving spring is double sided, having part of a make contact pair on one side and part of a break contact pair on the other (See Fig. 4.) Break-make assemblies are often referred to as "change over contacts." It is usually intended that the break contacts shall separate before the make contacts close, but in the Siemens type of spring set (where exact gauging is not specified) it is possible that a "make-before-break" action may occur. Thus, in cases where the circuit demands a particular order of operation of a break-make, a special adjustment note must be added to the adjustment chart in the case of Siemens type relays.

Make-before-break Contacts (abbr. "MbB").

This order of operation may be achieved in one of three different ways

1. As indicated in the previous paragraph, a break-make assembly of the Siemens type may be used as a make-before-break, provided that a special adjustment note regarding the order of operation is added. When adjusting these contacts, the make contact is brought close to the moving spring (say 10 mils contact clearance) and the break spring is so tensioned that it "follows" the moving spring without "breaking," until the make contact has made a firm connection.

2. If it is desired to ensure the correct action without depending on special adjustments, the special types shown in Figs. 4 and 7 are used. It will be seen that the break contacts are separated by the movement of the upper spring of the

make pair, so that there is no possibility of the break action occurring before the make, no matter what the adjustment may be. This arrangement involves the use of a special make spring with two contacts, one of which takes part in the breaking function also. Since the opening of the break contacts must take place after the make contacts have closed, the travel of the moving spring must be comparatively large. In some cases an additional break contact is associated with the moving spring, making a break-make-before-break assembly; the construction is seen from the conventional representation shown in Fig. 9.

3. Owing to the somewhat complicated variations of contact pressure which occur during the functioning of the above type of MbB assembly, "bounce" of the contacts for a few milliseconds is difficult to avoid. For this reason, where the circuit demands clean operation, separate make and break assemblies are used; the correct sequence of operations is again dependent on adjustment, but this is much easier to obtain with independent spring sets than with the combined break-make assembly. A general consideration of contact bounce is given later.

Double-make Contacts.

It is sometimes necessary for two make contact springs to be associated with one moving spring. In this case the springs are arranged in the order represented in the schematic sketch in Fig. 9. Thus, as the relay is operated, the moving spring makes contact with the first make spring and then presses that make spring into contact with the second make spring. The first make spring has contacts on both sides for this purpose.

Twin Contacts.

These should not be confused with "double make" contacts, or with the "make" spring of the MbB assembly, which has two contacts on one spring. A relay spring having twin contacts is shown in Fig. 4, from which it is seen that two pieces of contact material are placed side by side, the one merely duplicating the function of the other. The object of this arrangement is to reduce the possibility of circuit failure due to dirty contacts. It has been found

that, in the majority of cases during the normal life of a relay contact, disconnection faults due to dust, etc., occur momentarily, and then quickly disappear after one or more operations of the relay; the possibility of both of the twin contacts being disconnected at the same time is remote.

There are disadvantages, however, which must not be overlooked. The twin contacts share the total spring tension, and therefore the contact pressure of each will be less than that of the corresponding single contact. Moreover, the sharing may be unequal, causing an excessive number of faults on the one with the least pressure. It is for this reason that the end of the spring is split a short way between the contacts to allow each a little independent motion of its own. This independence must not be given too freely, however, or else it becomes difficult to gauge the twin contacts to make and break at the same time, and one of them may take more of the wear than the other.

Buffers.

It has been mentioned in the description of the construction of the Siemens type relay, that parallel with some of the contact springs there are short thick strips, which act as "back-stops" or "buffers" to the springs. The primary object of these buffers is to ensure good contact pressure, and they are placed against all springs which are not already supported when in the normal position. Thus, in a make contact assembly, both springs generally have buffers below, but if the assembly is a break-make, then the buffer is omitted from the moving spring, because the break spring takes over the back-stop function. The buffer for the break contact in an MbB assembly is usually above the spring and is really a front-stop, because it comes into use only when the relay is in the operated position. The contact springs are bent into a slight curve before assembly, so that there is a known tension between spring and buffer when the complete spring pile is tightened up. An engineer adjusting such a relay can then be certain that there is at least that tension, in the form of contact pressure, so long as the spring is lifted off the buffer, no matter how slightly.

Buffers are not provided on the A.T.M. type of relay, and their place is taken by the use of thicker contact

springs and an exact adjustment specification for the movement and follow of the contacts when operated. This scheme (known as "gauging") is described in the next chapter.

Contact Bounce.

The term "bounce" has been applied to the momentary chattering of relay contacts when they make or break. The duration of contact bounce is usually of the order of 1 to 10 milliseconds (thousandths of a second), and very few relay contacts are free from it unless some special precautions are taken. Looking at the problem from a general point of view, it will be thought that a pair of contacts, both mounted on thin springs, are sure to bounce, and, on the other hand, contacts mounted absolutely rigidly are equally liable to this fault. Between these two extremes there are many alternatives, and some of the theories which have withstood practical test are given here.

On Siemens type relays the use of buffers helps in the reduction of contact bounce in certain cases, chiefly because the buffer acts as a damper against spring vibration.

On A.T.M. type relays (without buffers) it has been found that bounce can be eliminated on make contacts if the make spring is fairly thick, 30 to 40 mils. Thus the full pressure is obtained on the contacts almost as soon as they touch, the shock being taken by the short section of the thin moving spring beyond the tip of the armature lever. This type of make contact is not suitable for large spring piles because the stiff make spring often prevents the armature from taking its full stroke, and it would be difficult to ensure that all the contacts in the pile were operated. It may be used on selector impulsing relays, however, because a single spring assembly is used and it is most important that contact bounce shall be avoided.

Bounce on break contacts without buffers is difficult to eliminate entirely, because when the relay releases and the armature lever is out of engagement there is no control over the vibration of the moving spring, but as a rule it can be reduced by increasing the contact pressure. During the release of a relay, the make and break contacts open and close at different points in the return stroke of the armature, and this produces complicated variations in the

tensions of the springs and in the restoring force on the armature. This frequently causes oscillation, which shows up in the form of "contact bounce," particularly in the case of break contacts at the bottom of the spring pile.

There is one other form of bounce which may occur on the A.T.M. type of relay, and that is bounce of the armature lever on the back stop when the relay is released. This bounce, if excessive, will open the first break contacts. It can be avoided, however, by adjusting the back stop so that, in the resting position, the armature has no "play" between the back stop and the armature lever, because, under these conditions, any tendency to bounce is quickly damped.

On MbB contacts, bounce frequently occurs on the break. It is worse than on ordinary break contacts, and although the exact theory is not known, it appears that one of the contributory causes is the supporting of the top spring at two different points, first at the make and then at the break, thus introducing a somewhat complicated flexing of the spring.

Contact Materials.

The contacts on the early manual type relays were made almost universally of silver, and although this metal tarnishes, the sulphide which forms is a conductor of electricity and is not detrimental. Modern relays used by the General Post Office in this country have either platinum, in the case of heavy loads, or some alloy of silver for more general work. The alloy used is that commonly known as "P.G.S." consisting of 7 per cent platinum, 67 per cent gold, and 26 per cent silver. The approximate ratio of costs of relay spring contacts is. for silver 1, P G S 4, platinum 24, whilst for tungsten, which is considered later, it is 16. In view of the costliness of platinum, springs fitted with contacts of this metal are identified by having a small V-notch cut in the end, however, on close inspection, platinum contacts can be distinguished from P G S. by their whiteness as compared with the slight yellow tinge of the alloy. On circuit diagrams, etc., the contacts which are of platinum are often marked "Pt" or with an asterisk.

The most common shape of contact on early relays was

a "pip" or cone for one electrode and a "plate" or shallow disc for the other. These were connected to negative and positive potentials respectively, because it was believed that the principle of the arc lamp would apply, viz., that metal would be taken from the positive pole and deposited on the negative. Unfortunately, for reasons as yet unexplained with any exactitude, this does not occur consistently, and therefore the dome shaped contacts, all of equal size, are now employed in this country. The relative dimensions of

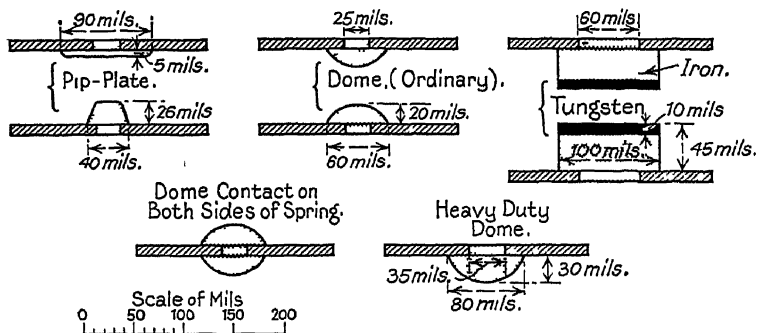


FIG 14. SHAPES OF CONTACTS

the two shapes are shown in Fig. 14. Specially large dome-shaped contacts are used occasionally in cases where the relay is operated so frequently that renewals would otherwise be required too soon, an example of this being a Director *A* relay, which makes $13\frac{1}{2}$ million operations per annum. The contacts are fixed to the spring either by spot welding, or by riveting a shank formed on the back of the contact as illustrated.

Platinum is now used for breaking all magnet circuits (and also for making, if contact bounce is present), and durability tests have shown an average of 15 million operations when interrupting a 46 ohm magnet at 50 volts with a suitable spark quench. If the contact is free from bounce as many as 60 million operations may be obtained.

Contacts of P.G.S. are not used for breaking currents greater than $\frac{1}{2}$ ampere; usually much less, and tests have shown a life of about 30 million operations when breaking

the circuit of an 800 ohm relay at 50 volts (unquenched) A slightly shorter life is obtained from silver contacts under such conditions.

Tungsten is rarely used on telephone relays, but is sometimes fitted on heavier telephone equipment, notably self-drive rotary magnets on two-motion selectors and on uniselectors. These magnets have a single make or break contact, and in order to obtain freedom from contact bounce at high hunting speeds a heavy contact pressure is employed. In addition to being able to stand up to severe hammering, tungsten can break heavy currents up to 5 amperes without undue wear, and is therefore used in cases where the carrying capacity of platinum is exceeded. Tungsten is obtained usually under the trade name of "Platit," which consists of 99 per cent pure tungsten and 1 per cent of various impurities which do not affect appreciably the properties required of an electrical contact. Tungsten contacts carrying 1 ampere in an inductive circuit (quenched) have been operated 100 million times without destruction. The metal is extremely hard and cannot be riveted or welded direct to the contact springs in the same way as the other types of contact. It is usual to weld it on a disc of iron or mild steel and rivet the iron to the spring. Typical dimensions are shown in Fig. 14.

The resistance of relay contacts is normally of the order of 0.001 ohms, and if a fault occurs the resistance jumps usually to many hundreds of ohms without any intermediate stages. Tungsten is an exception not only in giving resistance faults of the order of 10 or 20 ohms, but also in being sensitive to contact pressure, at less than 5 grammes resistances greater than 1 ohm are common, but at normal pressures for tungsten contacts, e.g. 50 grammes, the resistance is of the order of 0.2 ohms.

The wear of all types of contact is due almost entirely to the action of the current which is broken when they separate. Thus, contacts which carry little or no current can be operated for an indefinite period without deterioration, and even when the pressure is 100 grammes or more the flattening of dome-shaped contacts is very slight. Chemical corrosion of the contacts occurs very little, owing to the stable nature of the materials used, but if contacts normally

separated are left unoperated for a considerable time, failure may occur owing to a film of dust, etc., collecting on the surface. For this reason relays are usually more reliable when used continuously than when left idle for long periods.

It is curious to note, however, that even the slightest oxidation will introduce a "coherer" effect, which causes an almost complete disconnection under low voltage conditions only. As a result of this it is not desirable to allow contacts to carry small speech currents without superposing a D.C. potential greater than 1 volt. Faults from this cause do not occur very frequently with ordinary relay contacts, and the coherer effect becomes important only in the case of brass to brass contacts, e.g. selector wipers.

Under conditions of heavy load pairs of contacts wear away, forming a crater on one or both sides, thus producing a receptacle for dust and other non-conducting particles, in many cases small globules of contact metal are also visible on the spring at the base of the contact, indicating that the metal has been molten and has been splashed in all directions. This applies to normal circuit conditions, but if welding occurs, as described in the next section, then "wear" frequently results, due to portions of one contact being wrenched off and attached to the other, and, in extreme cases, one contact, complete with rivet, may be pulled right out of its spring.

Contacts of brass, carbon, tungsten, or mercury as used on Motor Start relays are dealt with on page 80.

Spark Quenches.

The breaking of currents greater than $\frac{1}{2}$ ampere in an inductive circuit usually produces a destructive spark at the contacts. The inductive energy stored in the circuit tends to prolong the passage of current after the contacts have separated, and, according to the current and voltage conditions which prevail, either a momentary arc or a spark results.*

The object of a spark quench circuit is to provide a by-pass for this inductive energy, and this may be effected

* For further information see "Sparkling and Arcing at Relay Contacts" (Jacquest and Harris); Inst. P.O. Elec. Engrs., Paper No. 118.

rapidly by means of a condenser shunted across the contacts. This condenser charges up when the contacts break and thereby absorbs the energy which otherwise would be dissipated in the form of a spark. A similar effect occurs if the condenser is shunted across the coil. This would constitute a perfect spark quenching device were it not for certain disadvantages when the contacts re-closed. As the condenser would be charged up to the full battery potential when the contacts were open, it would be discharged when the contacts made, and if there were no series resistance

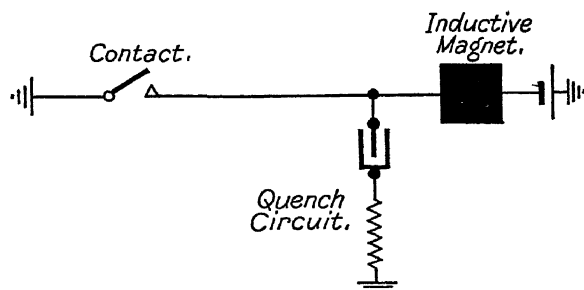


FIG. 15. SPARK QUENCH CIRCUIT

in the circuit the discharge current, although momentary, would be extremely large. It has been found that this heavy current, passing through the inherent small resistance of the contact, would generate so much heat that platinum or other contacts would melt slightly where they touched, and would become welded together.

This welding is not always sufficient to prevent the springs from separating under their own tension, but when they did separate, a portion of one contact would be torn off and deposited precariously on the other, resulting in rapid destruction of the contacts. It can be guarded against by inserting resistance in series with the spark quench condenser, as shown in Fig. 15. Although this resistance prevents welding, it detracts from the efficiency of the condenser in absorbing the spark energy, so it is necessary to decide on the optimum value of capacity and resistance for every material and every circuit.

The usual circuit which requires "quenching" in telephone practice is that of a 46 ohm selector magnet or of a 75 ohm unselector magnet broken by platinum contacts at 50 volts, and the standard spark quench for this and similar circuits has been fixed at 1 μ F. and 200 ohms. In those few cases where P.G.S. is used for such circuits the best spark quench is 1 μ F. and 10 ohms.

Tungsten has a much higher melting point than the other contact materials and therefore does not require such a high resistance in the circuit for the prevention of welding; also a larger condenser may be used. A suitable spark quench for tungsten contacts is 4 μ F. and 0.5 ohms, but frequently the normal resistance of the connecting wires is sufficient, so that the separate resistance may be omitted.

An alternative spark quenching device is the shunting of the magnet coil with a non-inductive resistance. This principle is adopted for the selector release magnet, which has a 100 ohm winding shunted internally by a 500 ohm non-inductive winding, so that the effective resistance at the coil tags is 83 ohms. The non-inductive shunt provides the by-pass for the inductive energy when the magnet is released, but the energy is dissipated so slowly that it increases the releasing time of the armature, and is therefore not suitable in all cases.

CHAPTER III

MECHANICAL ADJUSTMENTS

Adjustment by Tension Gauge (Siemens).

THE adjustment of relays is concerned mainly with the spring piles, but reference will be made later in this chapter to adjustments of the armature and other parts of the magnetic circuit. The current tests or "current adjustments" will be considered mainly in Chapter VI, dealing with Relay Design.

The main adjustment on Siemens and R A.T. type relays is by means of the tension gauge, ensuring that the correct contact pressures are obtained. The G.P.O. standard tension gauge is shown in Fig. 16. The testing pressure is obtained from a spiral spring, which is fixed at one end to

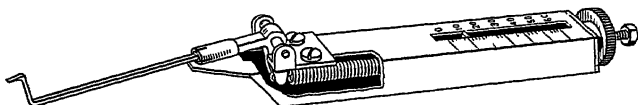


FIG 16 TENSION GAUGE

an adjusting screw. At the free end is a bell crank lever, which transmits the tension to a long pointer. The natural tension of the spiral spring may be varied by means of the adjusting screw until a given pressure on the pointer (say the pressure of one contact on another) is balanced by the natural tension of the spiral spring. This condition will be revealed by the pointer "floating" between its back stops, and the pressure exerted will be indicated on a scale which, although calibrated in grammes, really indicates the extent of the stretch in the spiral spring. Some other types of tension gauge depend on the deflection of a flat spring, but the method of use is similar.

It will be appreciated that, with a pair of springs of different thicknesses, the "contact pressure" which is measured by lifting one spring until the contacts separate may be different from that measured by depressing the other, and

neither of these tensions may represent the true contact pressure; but when one spring is quite rigid so that there is no "follow," the pressure, as measured by the slight deflection of the adjacent thin spring, is equal to the actual contact pressure between two springs. The "contact" pressure specified is usually that required to lift a moving spring from a break spring, or a make spring from a moving spring; in the case of the break contact of an MbB assembly, it is the pressure required to lift the combined make and break spring from the break spring. The pressure between spring and buffer is measured by moving the spring away from the buffer, and since the buffer is practically rigid this is the truest method of measuring *minimum* contact pressure.

The fault liability of contacts is increased rapidly as the pressure is reduced below 10 grm., and this is considered to be the lowest permissible. To cover variations of adjustment in practice, a higher value than this should be specified and Messrs Siemens quote 15 grm. minimum for their class B springs (12 mils thick) and 20 grm. minimum for their class C springs (16 mils thick). These two spring thicknesses are the most commonly used; other cases have special contact pressures specified on their adjustment charts. These pressures have a significance not only with regard to the reliability of the contacts, but also in the determination of the operate current. The value of current at which the relay will be operated is dependent on the tensions of the moving springs, and, therefore, when a relay is adjusted by tensions the operate current becomes a subsidiary test, and is used only as a check on the accuracy of adjustment of the springs. For this reason the minimum operate current specified on Siemens relay is usually well in excess of the normal capabilities of the relay.

In association with adjustments by tension gauge, it is necessary to ensure a correct clearance between the contacts in order to avoid arcing, and also to allow some margin of adjustment before the contacts fail to open. A minimum clearance of 10 mils is desirable, and Siemens type relays are usually specified to have 15 to 20 mils. In conjunction with this the armature travel must be considered, although for all normal relays Messrs. Siemens have a standard travel of 32 mils, measured between the core face and

the residual screw in the armature when in the un-operated position. If the contacts are required to operate in sequence (i.e. x and y contacts), this travel is increased to 43 mils. (For the determination of clearance and travel see page 46.) In the normal resting position there should be a slight clearance, nominally 2 mils, between the ebonite pip on the upper limb of the armature and the brass lifting pin of the first moving spring, to ensure that the first moving spring is resting on its break contact, or on its buffer, without interference. A similar pip clearance is also required between successive moving springs in each pile for the same reason. When measuring armature travel, however, the first pip clearance is taken as zero; thus a thickness gauge of the requisite size is inserted in front of the core face, the armature is pressed close to it, and in this position the ebonite pip on the armature should just touch the lifting pin. For a description of the gauges used for these tests, see page 42.

It should be noted that a long travel involves "rub" or "wipe" between contacts when "made," because the springs are virtually "pivoted" at different points. This may assist somewhat in cleaning the surface of the contact metal, but if carried to excess may have the opposite effect of collecting dust which has settled on the face and sides of the contact.

Adjustment by Thickness Gauge (A.T.M.).

The A.T.M. type of spring assembly is adjusted quite differently from the Siemens type. Since buffers are not used, the make contact pressure may be obtained by measuring the amount of deflection of the springs, break contacts are considered in the next section. The method is known as "gauging," although, more strictly speaking, it should be referred to as "space gauging" or "thickness gauging."

There is no convenient fixed datum for measuring the spring movements directly, but the lever effect of the rocker armature produces a useful alternative in the form of the gap between armature and pole face at various stages of operation of the relay. Thus, a statement that a contact "breaks at 10 mils," means that the contacts separate when the relay is operated with a 10 mils thickness gauge inserted

between the armature and the core, the residual screw, if fitted, is considered as part of the armature for this purpose. Similarly, a contact which "makes at 6 mils" closes when the relay is operated with a 6 mils gauge in front of the core. It must be remembered that, when the relay operates normally, the breaking at 10 mils occurs earlier than the making at 6 mils. In other words, when unoperated, the relay is at a large gauging, which is equal to

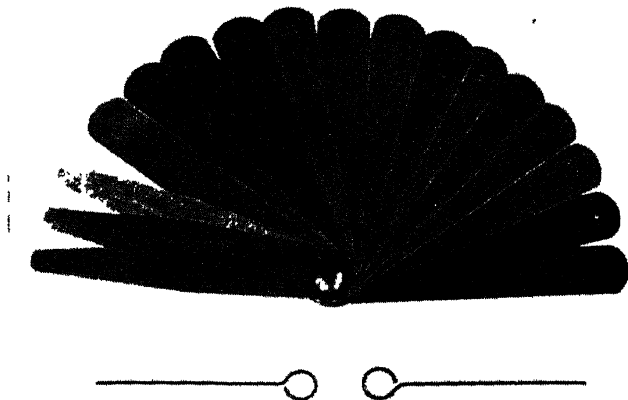


FIG. 17. THICKNESS GAUGES

the "travel" or "stroke" of the armature, when operated, the gauging is zero. It is preferable to operate the relay electrically rather than by hand for these tests, in order to obtain the true working conditions, especially in cases where the armature bearing pin is worn. The G.P.O. standard thickness gauges consist of flat strips of steel, approximately $\frac{1}{2}$ in. wide and 3 in. long, and are supplied in sets of various thicknesses from $1\frac{1}{2}$ mils upwards (Fig. 17). They are shown clamped together temporarily by means of the hole at the lower end of each.

The method of denoting spring gauging on adjustment charts is shown in Fig. 18. The charts refer to R.H. relays with standard gauging, that at (A) being for a

normal armature with 3 : 1 ratio, and that at (B) for a 2 : 1 ratio; also, the relay depicted at (A) has a double lever armature, and therefore two spring piles. Considering this relay first, it will be seen that to the left of the first spring of the upper pile is inserted the figure "22," which denotes the armature travel in mils; travel is always specified on relays which have make contacts that operate first, because the moving spring rests against the armature lever and the travel determines the contact opening. Between springs 1 and 2 is the figure "18," which is the gauging at which the x contacts must touch. Similarly the remaining make contacts, 6 and 7, and 8 and 9, are shown to have a gauging of 6 mils each, indicating that they operate simultaneously. Satisfactory make contact pressure is assured by the fact that, after making, the springs are moved 18 mils by the armature, i.e. 6 mils (gauging) \times 3 (the armature ratio). The actual tension resulting from this movement depends on the cube of the thickness of the spring. A table of spring thicknesses is given later.

Gauging of Break Contacts (A.T.M.).

Break contact pressure is dependent on the natural tension of the moving spring against the break spring when the relay is unoperated. As buffers are not used, the break spring is made much stouter than the rest in order to provide a semi-rigid support against which the moving spring may rest. The downward pressure of the moving spring itself is controlled by a current test on the relay as a whole, namely, a specification that the moving springs must be tensioned down so stiffly that the relay will not operate at less than a certain figure, called the "non-operate" current.

There is a further requirement, however, if more than one break contact is included in a single spring pile. Upon examination of the upper spring pile in Fig. 18 (A), it will be seen that the first break has a gauging of 11 mils, and the second break (part of the break-make assembly) has a gauging of 10 mils; if there were four break contacts they would have 13, 12, 11, and 10 mils in succession, 10 mils being the minimum in most cases. (The BMbB is an exception.) This means that as the relay releases, the outside break

contacts close first, followed by the remainder in definite sequence, and because each break spring is rigid, it prevents its corresponding moving spring from travelling any nearer to the armature. The result is that the moving springs become separated slightly (the loosely fitting collets allow this), each resting on the corresponding break contact with its normal tension. This is shown diagrammatically on the chart.

In addition, there should be a small clearance (2 mils) between the armature lever and the moving spring of

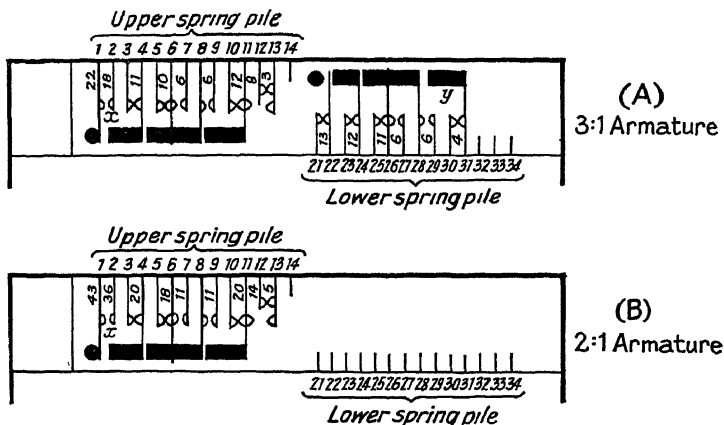


FIG. 18. STANDARD GAUGING ON A.T.M. RELAYS

the first break contact assembly when in the operated position. Assuming, therefore, that the spring load corresponding to the non-operate current is shared equally by the several moving springs, the break contacts will each receive their correct pressure. By contrast, it will be appreciated that if, on release, all the break contacts were to close at the same time, it would be impossible to say which of them were receiving the combined pressure of several moving springs and which were receiving none.

For the purpose of determining the total pressure of all the break contacts, the "non-operate" current test should be a measure, not of the armature load when the moving springs are at rest, i.e. supported, but of the combined

tensions of the moving springs without any support from the break springs, i.e. when all the break contacts have just separated. This test cannot be carried out because of the separating of the break contacts at different times, and in practice a compromise is accepted by allowing just a few of the break contacts to open during the non-operate test. For example, on a single-arm relay having three or more break contacts, the first two contacts may break with the specified non-operate current, and a similar scheme is adopted for a double-arm relay, although in that case the maximum number of contacts to be opened is one in each spring pile.

Make-before-break assemblies are considered quite separately from the other contacts in the spring pile, the gaugings being arrived at largely with a view to obtaining correct functioning of the contacts within the assembly. The figures shown on the chart are typical

Gauging of Complete Spring Piles.

In the case of mixed contact assemblies in a single spring pile, it is usual to place breaks first, then break-makes, makes, and finally MbB assemblies. This enables the gauging to be arranged conveniently and, in some cases, also enables the tensions of the moving springs of the upper make assemblies to assist in the provision of a good pressure on the break contacts. Exceptions are made only in the case of x or y contacts, where the order of operation must be considered, e.g. springs 30 and 31 in the relay shown in Fig. 18 (A). The use of a 2.1 armature in place of the normal 3.1 armature, considered in the previous section, involves different gauging figures, as can be seen by comparing the two relays in Fig. 18, but the general scheme of adjustments is unaltered.

The thicknesses of springs for the various functions have been standardized by the A.T.M. Co. into various "classes," the two which are most common at present being set out below. Class 1 is used for all general purposes, but Class 3 is used for most slow releasing relays where spring tension has to be reduced to a minimum.

As a rule there is no distinction between the gaugings for Class 1 and Class 3 spring sets, but special relays, such

as impulsing, two-step, or shunt-field relays, have not only special gauging, but also special spring thicknesses.

Function of Spring	Class 1	Class 3
Moving springs	12 mils	10 mils
α makes	12 "	10 "
Makes	16 "	10 "
First break	24 "	32 "
Subsequent breaks	24 "	24 "
Double contact springs on MbB's	12 "	10 "

Other Gauging Adjustments.

The determination of the contact clearance on Siemens type relays, as mentioned previously in connection with tension adjustments, is carried out by direct measurement, not by the system of armature movements. If thickness gauges of the normal broad-bladed type are used, it is difficult to observe whether the contacts are being deflected by the insertion of the gauge or whether they are just touching. An advantage is gained, however, by using the small wire type gauges seen in Fig. 17. Armature travel is measured, as usual, by means of broad-bladed gauges.

Residual gap, i.e. the projection of the residual pip or screw beyond the inner face of the armature is measured by direct gauging, and, in order to cater for the possibility of non-alignment of core face and armature, it is desirable to use a thickness gauge with a hole punched in one end. All the gauges shown in Fig. 17 are provided with this facility, the hole being used for clamping them together. The method of measurement is to insert the gauge under the armature with the residual screw projecting through the hole, and then to press the armature hard up to the core by hand. If the gauge is larger than the residual gap, it will be held rigidly between armature and core; if it is smaller, the gauge will be slack, if the thickness gauge is equal to the residual gap, it will be so held that there is just sufficient freedom for it to slide between the armature and core face, within the boundaries imposed by the hole in the gauge through which the residual screw is projecting. Three-pip residuals of the Siemens type are measured in a

similar manner, except that a thickness gauge, with a narrow tip (Fig. 17) is used. The tip of the gauge is inserted between the residual pips, and the "sliding" test is carried out as before.

It should be noted that the armature cannot be operated electrically for these tests, because the standard gauges are magnetic and would be attracted tightly against the core.

The hinge air-gap between armature and yoke is adjusted to the $1\frac{1}{2}$ mils usually specified, by first loosening the fixing screw of the bracket which holds the armature bearing pin to the yoke, then inserting the $1\frac{1}{2}$ mils gauge in the gap, operating the armature electrically, and finally tightening the bracket-fixing screws with the armature in this position. For this test the residual screw, if adjustable, should be withdrawn in order to ensure the minimum gap under the worst conditions.

Tolerances on gauging adjustments are normally ± 2 mils, but there are limitations in the case of spring assemblies which have a special order of operation, e.g. BM or MbB, and also in other cases where the gauging figure is small. A notable example is the " $1\frac{1}{2}$ mil" residual gap, which may be interpreted as "greater than 0, but less than 3 mils."

Adjustment Tools.

For the purpose of making the adjustments detailed in the preceding paragraphs, a number of special tools are available, and a brief selection of the tools required are described below together with some indication of the method of manipulation. The tools required for armature adjustments are shown in Fig. 19 and those for spring adjustments in Fig. 20.

(A) The bending tool for A.T.M. type armatures consists of a flat strip of steel, at each end of which is a shallow groove, which can be made to engage firmly with the armature lever. Provided that the armature hinge is fixed rigidly on the relay yoke a good purchase can be obtained for bending the arm to get the specified armature travel.

(B) The bending tool for Siemens type armatures is necessarily quite different, and as the armature can be removed from the relay quite easily, and can be replaced accurately without further gauging because of the knife

and armature proper can then be adjusted with the fingers quite easily, and the armature can be replaced and adjusted alternately until the correct travel has been obtained. Care should be taken to bend the armature only at the V-bend, and therefore the vertical pins of the tool should be as near to the bend as possible.

(C) The guide for introducing Siemens type armatures under the spring piles is merely a flat strip of xylonite, which can be used in the same way as a "shoe horn." It is of great assistance in the case of large spring assemblies, and prevents damage to the lower springs when replacing the armature.

(D) A spanner for the adjustment of residual screw locking nuts is required. In place of the ordinary double-ended spanner illustrated, a special combination tool is sometimes used, consisting of a box spanner, for the locking nut, and a small screwdriver in the centre for adjusting the residual screw itself.

(E) Screwdrivers of normal pattern are necessary for the holding screws of the spring assemblies as well as for the residual screw

(F) Straight duckbill pliers are used for bending contact springs, provided that easy access can be obtained to the sides of the spring. They have a broad nose, $\frac{1}{16}$ in. across, but the thickness of the limbs is very small at the tips; this enables a spring to be manipulated without undue interference with the neighbouring springs

(G) Bent duckbill pliers, as their name implies, are similar to the above, except that the nose is bent at an angle to facilitate access to springs on relays which are mounted very close together. Although these duckbill pliers are described as bending tools (and these remarks refer also to the special spring bending tools described below), the correct method of adjusting a spring is not by bending alone, but by "stroking." If a contact is adjusted by bending the spring at one point only, the deflection of the spring is concentrated at that point, with a consequent liability to fracture, especially after several readjustments. moreover, the "humped-back" shape which results may cause adjacent springs to touch. If, however, the spring is first gripped with the tool near the fixed end, and the bending action is

accompanied by the drawing of the tool along the spring with a "stroking" motion, the spring is bent evenly into

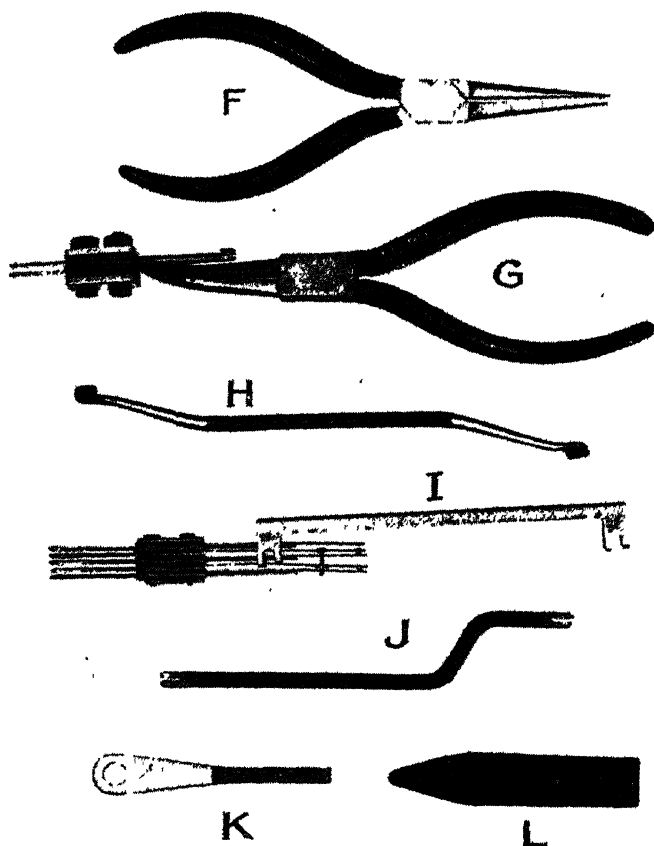


FIG. 20. TOOLS FOR SPRING ADJUSTMENTS

the form of a curve instead of a humped-back, and the disadvantages mentioned do not arise

(H) An alternative spring bending tool for A.T.M. type relays consists of a bent steel bar, at each end of which is

a thicker projection slotted to take a spring of average thickness. This takes the place of the bent duckbill pliers, and although the spring is gripped loosely instead of rigidly the combined bending and stroking motion can be carried out quite easily. A double-ended tool is provided to suit either R.H. or L.H. relays.

(I) An alternative spring bending tool for Siemens type relay is claw shaped, and grips both sides of the spring at once. This method is rendered possible by the use of parallel sided contact springs. The tool is again double-ended, but in this case the two ends differ only in the relative lengths of the pairs of claws, one end being suitable for depressing springs towards the armature, in the manner shown in the illustration, and the other for bending the springs in the reverse direction. This type of tool can be used for adjusting a centre spring pile, where the pliers are useless because of the lack of free space at the side for manipulation.

(J) A special bending tool for A.T.M. type back stops is necessary, because of the small clearance that exists between relays when mounted. It consists of a flat strip of steel, offset for convenience, and slotted at each end to engage with the front edge of the back stop. This type of tool can also be used with discretion on contact springs.

(K) The contact cleaner is a short strip of steel slightly roughened at one end. This roughening is little more than a "matt" surface; it should be noted that, on the small contacts normally used, a file is quite unnecessary and should not be used under any circumstances.

(L) The contact insulating wedge, although not an adjustment tool, is an important part of the tool kit. It is merely a flat strip of smooth vulcanized fibre for inserting between normally made contacts when it is required to insulate them for circuit testing reasons (see page 102). On no account should slips of paper be used for this purpose, because microscopic fragments of the paper cling to any rough surfaces on the contacts and produce intermittent faults which are very troublesome later.

CHAPTER IV

INDUCTIVE EFFECTS

Fast Relays.

THE "Standard Fast" relay is the normal type used in automatic telephony, and is so called to distinguish it from the slow-operating or releasing relays considered later. A brief consideration is necessary to show why it is fast in action, as compared with others.

Fig 21 (a) shows in diagrammatic form the path of flux in the magnetic circuit. When the current is switched on, the rising flux generates a back E.M.F. in the turns of the winding, so that the current i rises according to the well-known Helmholtz Law—

$$i = I \left(1 - e^{-\frac{Rt}{L}} \right), \text{ where } \begin{cases} I = \text{final steady current, } \frac{E}{R} \\ c = 2.718 \\ R = \text{resistance of winding} \\ t = \text{time measured from start} \\ L = \text{inductance of winding} \end{cases}$$

The inductance is proportional to the square of the turns, and the value $\frac{L}{R}$ is known as the time constant of the winding, since it is a measure of the time taken for the current to rise to a given fraction (approximately $\frac{2}{3}$) of its final steady value. A graphical record of the rise of current according to Helmholtz's Law would be similar in character to the curve marked "Current in Coil" in Fig 22.

In a fast relay there is little to prevent the rise of flux from following the same type of curve as the rise of current, except perhaps the small eddy currents in the metal parts in and around the relay, so the time constant of the electrical circuit is a fair indication of the time taken for the magnetic flux to reach the value at which the relay operates ("operate flux"). After the armature has been attracted, there is a further increase in flux beyond the equivalent current value, owing to the reduction of the air-gap between armature and core.

On disconnection of the circuit, the previously steady current drops to zero immediately, but the fall of flux is delayed by the eddy currents which are produced by the comparatively rapid flux change. The graph of the fall of flux is not quite the same as a Helmholtz curve, owing to saturation effects. The releasing lag is determined by the time taken for the flux to fall to a value at which the armature can no longer remain operated.

The release may be assisted considerably by the use of a large residual air-gap when the relay is in the operated position, as it reduces the normal value of flux when the armature is operated, but it also involves a shorter travel, or, if the armature is moved farther away to compensate for the space taken by the residual gap, a higher operate current. Small inertia of the moving parts is essential to fast operation as well as release, but this is found in all types of telephone relays. Operating and releasing lags as small as 5 mS. (milliseconds) are quite common, but a reasonable figure to assume for a fast relay with 3 or 4 spring assemblies is about 20–40 mS. (See Appendix I.) For a particularly fast operating lag it is necessary to use a “nickel-iron” relay (see page 60). Impulsing relays are considered separately in Chapter VII.

Slow-releasing Relays.

Fig. 21 (b) and (c) shows a relay which has part of its “winding space” at the heel end occupied by a “slug” or annular ring made of solid copper. This is equivalent to a short-circuited winding having one turn of extremely low resistance and, by the laws of induction, the effect is (1) to reduce the impedance of the main winding, and (2) to oppose, by means of an induced current in the slug, any change of flux in that part of the core which it surrounds (Lenz’s Law). This has little effect when the current in the main winding is first switched on, because the main flux can leak across the gap between core and yoke, as shown, until the inductive effect of the flux has died down; in addition, the reduced electrical inductance allows a faster growth of current in the coil.

On disconnecting the circuit the coil impedance plays no part, because the current drops to zero immediately, but

the tendency of the slug current is to maintain the flux above the releasing value as long as possible by means of the current induced in it. When considering the time lags of relays it is most important to separate "inductance" or impedance of the winding (affecting growth of current in the coil) and "eddy currents" induced in the slug (producing an opposing flux)

A method of producing a long releasing lag other than by the use of slugs is the lowering of the releasing flux. This may be achieved by reduction of spring pressures (i.e. thinner springs), by reduction of armature leverage from 3:1 to 2:1 (on A.T.M. type relays) and by the use of as few contact springs as possible. Also, the value of the normal steady flux which has to fall to the releasing value can be increased by the reduction of the residual air-gap. It is not desirable, however, to reduce the residual below $1\frac{1}{2}$ mils, as after a comparatively short time the residual screw wears a dent through the nickel or zinc plating of the pole face and the residual air-gap may become almost zero; this may reduce the reluctance so much that the relay will be operated permanently by the residual flux in the core and yoke. For the same reason special care should be taken on slow-releasing relays of the A.T.M. type to ensure the maintenance of the correct hinge air-gap.

A common releasing lag for this type of relay is 350–500 mS. A lag of 1,000 mS. (1 second) is not unknown, although this can be obtained only with light spring tensions and poor contact pressure. The application of this type of relay to selector impulsing circuits is given on pages 112 and 128.

Slow-operating Relays.

Fig. 21 (d) shows the distribution of flux when switching on the current in a relay which has a slug at the armature end. As in the previous case, the flux tends to leak across the space between the core and the yoke rather than pass through the slug, but the difference lies in the fact that the leakage is away from, instead of towards, the armature. Therefore, the relay will not operate until the back E.M.F. in the slug has died down sufficiently to allow the majority of the flux to traverse the armature air-gap, and a long operating lag is the result.

This is illustrated by the graph in Fig. 22. It is seen that when the circuit is connected, an opposing current is induced in the slug, thus causing the main flux, i.e. the flux in the slug (and in the armature air-gap), to rise very slowly. In

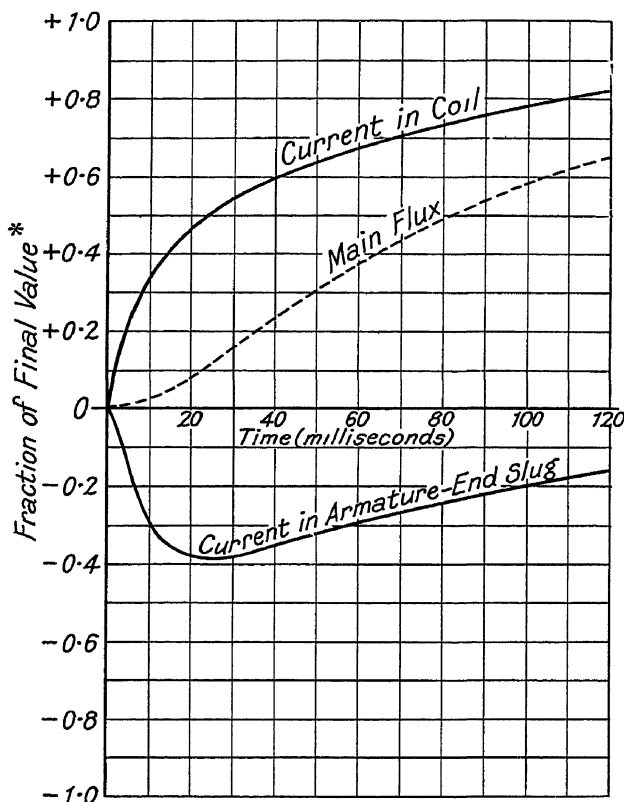


FIG. 22 CURRENT AND FLUX IN A SLOW-OPERATING RELAY

* Slug current is shown in terms of the equivalent coil current

spite of this, there appears to be some other rising flux which causes the coil current to be impeded right from the start in accordance with the Helmholtz Law of inductance effects; this is the leakage flux indicated in Fig. 21 (d).

It would appear from the consideration of the flux path in Fig. 21 (e) that the releasing lag in the case of an armature end slug should not be different from that of a heel end slug, since the flux produced by the eddy currents still tends to keep the armature attracted, but, in practice, the slow-operating relay is assisted by a heavy tension on the relay springs, whereas the slow-releasing relay has thin springs and light tensions. Even with heavy tensions it is difficult to obtain an operating lag greater than 150 mS. Operating lags of 50 to 100 mS. are more common.

Sleeved Relays.

Some relays have a copper slug which extends the whole length of the relay, the equivalent of an armature and heel end slug all in one, forming a "sleeve" completely covering the core. A "sleeve" is of lesser diameter than a "slug," and the coil is wound outside it. (See Fig. 21 (f).) The rise as well as the fall of flux is delayed by the back E.M.F.'s induced in the copper, and, therefore, the effect is not different in principle from that of the armature end slug.

A more common equivalent of the sleeved relay is the double-wound relay with one winding short circuited. The effects produced are not so great, but the double-wound relay is useful if it is desired to make the relay either fast or slow at will, this being achieved by suitable control contacts in the short circuit across the winding. Single coil relays may also be used in this way by shunting the coil with a resistance or another relay of low impedance, thus diverting the initial current on operation and preventing the immediate fall of current on release. The effect is particularly noticeable on the releasing lags of slow relays, an increase of 20 per cent in the time of a selector *B* relay being a common result of providing another relay in parallel.

For the G.P.O. standard method of representing slugs and sleeves in schematic diagrams, reference should be made to Fig 9.

Ringin Trip Relays.

This type of relay remains unoperated when ringing current at 16 cycles per second is passed through it, but

operates when direct current is superposed on the alternating current. A relay will not respond to the alternating current if it is slow enough in operating and releasing, and, therefore, ringing trip relays are provided with armature end slugs, and sometimes a sleeve in addition

The requirements are particularly severe in the case of the final selector *F* relay, which is inserted in series with the ringing current supply (Fig. 12). When a subscriber is being rung the alternating current passes, but, as the bell in the subscriber's instrument is in series with a 2 μ F condenser, the battery potential which is superposed on the A.C. is prevented from producing a direct current, and, therefore, the *F* relay remains unoperated. When the call is answered, the condenser in the subscriber's instrument is shunted by a low resistance, so that the direct current can pass and produce the operation of the *F* relay. Among the functions of the relay on operation is the "tripping" (disconnecting) of the ringing circuit; hence its name.

A double-wound relay is employed, having a "line" winding of 200 ohms for operating an *x* contact, and a "locking" winding of 1,300 ohms connected in series with the *x* contact and the exchange battery. This provides for sensitivity when working over long lines, and also enables the relay to be held operated after the line coil has been disconnected.

The greatest difficulty, however, is in the prevention of the ringing trip relay from operating falsely under A.C. conditions owing to abnormal surges of current which may occur in practice. For this reason it is preferable to test for non-operation by means of an A.C. circuit simulating working conditions rather than by a D.C. non-operate current test. Such a circuit is shown in Fig. 23. The *F* relay is shown in a skeleton final selector circuit, and is connected by means of a plug and jack to two parallel circuits, one of 1 μ F. in series with a 1,000 ohm inductive coil, and the other of 4 μ F. in series with a 1,000 ohm inductive coil shunted by a 1,000 ohm bell. This, together with a 100 ohm series resistance, represents the worst subscriber's circuit met with in practice. In addition, it will be noted that prior to plugging in to this test circuit, the condensers are charged to the 50 volt battery potential via the break

contacts of relay *K* which is connected to the bush of the jack. This is a condition which occurs in practice, and is included in the test because the subsequent discharging of those condensers and charging in the reverse direction may be a cause of premature tripping.

When, however, the D.C. test is used instead of the above, the usual test currents for *x* operation, measured on the 200 ohm winding, are:—non-operate at 23 mA., operate at 26.5 mA.; or, if measured on the 1,300 ohm coil

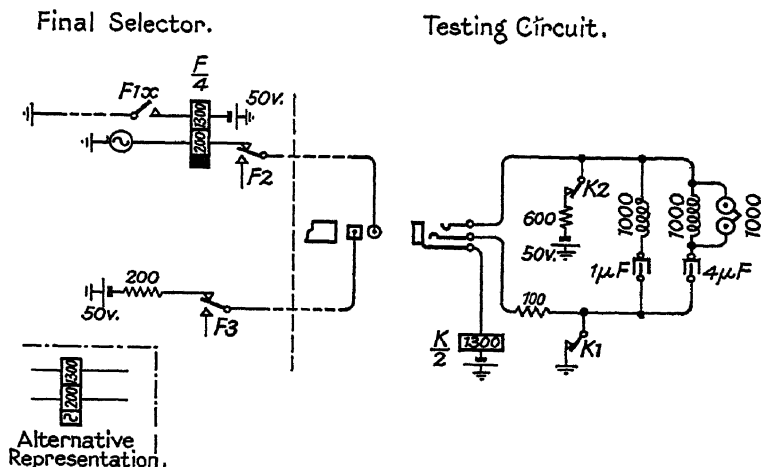


FIG. 23. RINGING TRIP RELAY, NON-OPERATE TEST

for convenience, non-operate at 9 mA, operate at 10.3 mA. The operate current test for the complete spring assembly, measured on the 1,300 ohm coil is 20 mA

The conventional method of representing ringing trip relays in schematic diagrams is usually the same as for ordinary telephone relays with armature end slugs but sometimes the "blocking" of the end is omitted, and the A.C. symbol is inserted as shown in the inset of Fig. 23.

Balanced Windings.

There are certain relays with a requirement of fairly high impedance; for example, the double-wound relay connected in the battery and earth feeds to a transmission line

(relays *A* and *D* in Fig. 59). High impedance is necessary to reduce as far as possible the leakage of speech currents both to and from the battery, which is common to an exchange. There is a further requirement, however, that the impedances of the two windings of a double-wound relay used in this way must be balanced at speech frequencies. It is not possible here to go deeply into the transmission reason for balanced windings, but it may be stated simply that it is to prevent overhearing and other inductive disturbances between one telephone circuit and another. The amount of unbalance usually permitted is 5 per cent, and a typical relay with D.C. resistance of $200 + 200$ ohms has an impedance of 5,000 to 10,000 ohms at 800 cycles per second.

In most manual telephone circuits, and in a few automatic circuits, two separate relays are used in place of the double-wound relay, thus permitting signalling on the two lines individually. If signalling is required on one line only, the contacts are omitted from the relay on the other line, so that it becomes merely a "retard." It will be appreciated that where two separate relays or retards are employed, they must be specially balanced and must not be separated. They are considered as a "balanced" pair; in other words, if one relay of a balanced combination is faulty, the pair of relays must be replaced.

Nickel-iron Relays.

When specially high impedance is required, the cores (and sometimes the armature also) are made of a nickel-iron or nickel-steel alloy (approximately 50 per cent nickel) instead of soft iron. These alloys have a higher permeability and a higher electrical resistance (to eddy currents), both characteristics producing a higher impedance in the winding. An example of a nickel-iron relay is relay *I* in the auto-to-auto relay set (Fig. 60). In many cases it is better to retain the soft iron core but to add a thin nickel-iron sleeve or several concentric sleeves. This is partly because the eddy currents will be confined to the skin of the core (or sleeve) nearest the winding, and also because the sleeve is less saturated by the normal D.C. flux, giving even higher permeability. Some measurements on nickel-iron sleeved relays (commonly known as "nickel-sleeved")

relays) show impedances at speech frequencies 50 per cent to 150 per cent higher than for similar relays with soft iron cores.

Another property of nickel-iron relays (26 per cent Ni) is a reduction in operating and releasing lags to about two-thirds their original value, the permeability of this alloy being less than in the previous case. Special relays are in use having releasing lags as low as 1 mS., but, as this is assisted by heavy spring tensions as well as nickel-iron cores, the operating lag may be increased to about 50 mS.

Laminated cores also obstruct eddy currents and increase the impedance for a given resistance, but they are not used normally in automatic telephony.

Silicon steel (up to 5 per cent silicon) has properties similar to nickel steel, although to a lesser extent, and is used only occasionally for relay work. It is better known in connection with telephone receiver diaphragms in the form of "stalloy" (4 per cent silicon, 0.2 per cent aluminium).

CHAPTER V

SPECIAL RELAYS

Two-step Relays.

THESE are so called because of their operation in two steps in the type of circuit shown in Fig. 24. Two separate windings are provided, the first (500 ohms) being so inefficient that it cannot operate more than the x contact, whilst the second winding (1,000 ohms) is sufficiently powerful to operate all the contacts when both windings are connected in series. Thus, in the circuit shown, the closing of

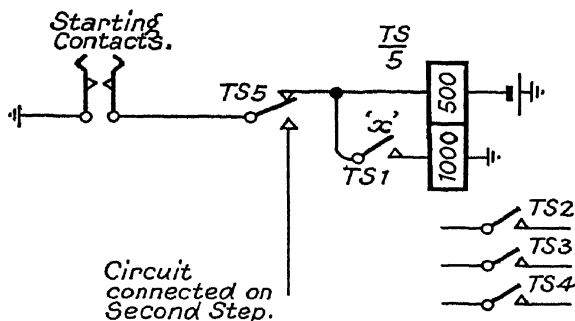


FIG. 24 TWO-STEP RELAY CIRCUIT

the starting contacts energizes the first winding to operate the x contacts, i.e. the first step, but the second winding receives no current owing to the short circuit via the starting contacts. On opening the starting contacts, however, the short circuit is removed and the relay operates fully, i.e. takes its second step, owing to the energizing of the two coils in series. In the example shown, the $TS5$ contact is utilized to divert subsequent operations of the starting contacts to some other circuit, the two-step relay remaining locked in the operated position.

In its broader sense, however, a two-step relay is any relay having an x contact assembly which is operated by

an initial small magnetic flux, and a main contact assembly which, together with the x contact, is operated by a subsequent greater flux. In general, it is not practicable to obtain two-step operation unless there is a large main spring pile giving a generous margin between the operate currents for the main and x contacts.

Shunt Field Relays.

These are double coil relays which will not operate when one coil only is energized or when the two coils are energized in opposite directions, but will operate when both are energized in the same direction. The coils are placed side

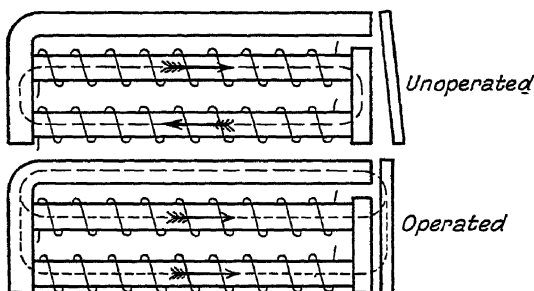


FIG 25. SHUNT FIELD RELAY (A.T.M.)

by side with a common yoke and pole face, as shown in Fig. 25, and the upper drawing shows the result of passing current in the windings in opposite directions. It will be seen that the flux circulates round a local path and does not affect the armature. A similar result is obtained by passing current through one winding only, because the air gap at the armature presents a higher reluctance than the core of the unenergized coil. The lower drawing shows the main path of the flux when the two coils produce fluxes in the same direction. In this case the twin coils act exactly as if they were one, as in an ordinary single coil relay, and the passage of the flux across the armature gap causes the armature to be attracted in the usual manner.

This type of relay is frequently used as a "polarized" relay, by having one winding permanently energized as a "polarizing coil." Thus the relay will operate or release

according to the direction of the flux in the other coil. The "permanent" polarized relay is described below.

Polarized Relays.

This term is applied to relays which contain a cobalt steel permanent magnet in series with the main magnetic circuit, and thus will operate only with current in one direction. The principle of construction of the single

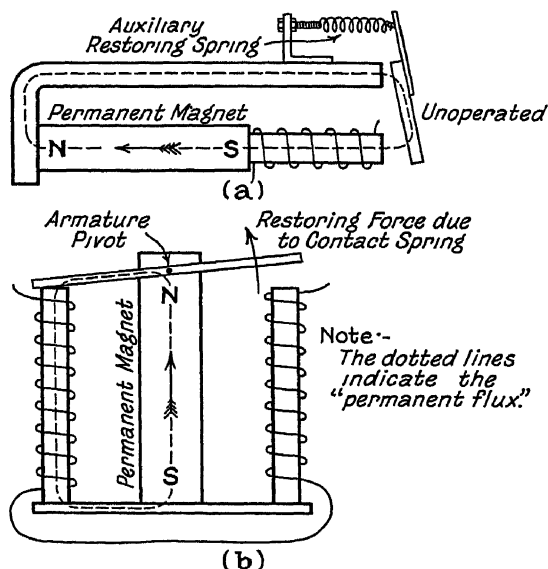


FIG. 26. POLARIZED RELAYS

coil type is shown diagrammatically in Fig. 26 (a), where it will be seen that, although the flux produced by the small permanent magnet tends to attract the armature to the core, it is prevented from doing so under normal conditions by an auxiliary spiral spring, which is mounted on the yoke as shown. When the direction of the current in the winding is such that the flux induced opposes the permanent magnet, then the resultant flux in the armature gap is reduced and the relay remains unoperated, but when the polarity is such that the flux adds to that of the magnet,

the tension of the spring which has been holding the armature back is overcome and the relay operates. This type of relay is used in coded call indicator working, and the contacts are of the rigid type as fitted to the marginal relays described in the next section.

It will be apparent from the foregoing description of flux conditions that if a very large current is passed through the coil in the non-operating direction the flux produced may exceed that of the permanent magnet, and then the armature may be attracted by the excess flux. This trouble may be avoided usually by designing the relay to suit particular circuits, but there is a polarized relay which, although being non-standard as regards overall dimensions and mounting, has the advantage of remaining unoperated, no matter how great the non-operating flux. It is merely an adaptation of the standard mechanism for subscribers' A.C. bells and is shown in Fig. 26 (b). In principle it consists of two relays, back to back, with a common yoke and a common double armature with a central pivot. The yoke itself is a permanent magnet, and the two coils are so connected in series that the flux produced by the current passes from one end of the armature to the other and does not traverse the permanent magnet to any appreciable extent. Thus, when current is flowing in the non-operating direction, the top of the left-hand coil in Fig. 26 (b) becomes a S. pole, and the top of the right-hand coil is a N. pole, producing attraction in the non-operating direction and repulsion in the operating direction. On reversal of the current, the polarities of the coils are transposed, and attraction takes place on the right-hand side of the armature and operation results. When no current is flowing, the armature may remain attracted to one or other coil according to chance, but, in practice, the restoring pressure of the contact springs (not shown on the diagram) ensures that the armature takes up the unoperated position.

The telegraph relay considered later is also a polarized relay.

Marginal Relays.

In certain circuits there is a very narrow margin available between the maximum current at which a relay must

remain unoperated and the minimum current at which it must operate. Such circuit conditions occur in coded call indicator working and, since a single contact assembly is all that is required, the relay shown in Fig. 27 is used. The coil and the magnetic circuit are identical with ordinary auto-type relays, but the contacts are rigid, the "moving" contact being fixed to the tip of the armature lever, whilst the "make" contact is mounted on a stiff spring, the position of which is controlled accurately by an adjustable

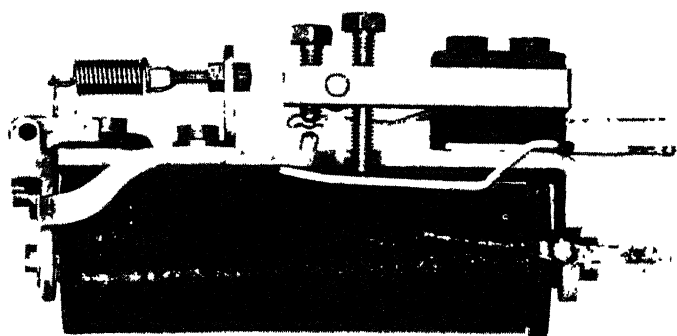


FIG. 27 MARGINAL RELAY (A.T.M.)

screw; the normal contact opening is only $2\frac{1}{2}$ mils. Adjustment of armature travel, normally 7 mils, is provided by means of a micrometer screw which bears on the back-stop spring, and the restoring pressure on the armature is provided by a spiral spring whose tension can be varied to meet the specified operating and non-operating conditions. Thus a very accurate adjustment can be made, and the relay can be depended upon to retain its characteristics for long periods.

Pendulum Relays.

This name has been applied to relays whose armatures are weighted in such a manner that the time lags are controlled on the principle of the pendulum. Standard

autotype relays may be adapted to this principle quite easily, as can be seen from the A.T.M. relay illustrated in Fig. 28; it is mounted on its side just as an ordinary A.T.M. type relay. The yoke is cut short, and the missing portion is replaced by a flat steel spring clamped at one end between the spring pile and the yoke, and fitted at the free end with an adjustable brass weight or "bob." In place of the normal armature, a fixed pole piece is provided, leaving an air gap between the pole face and the flexible steel strip which now forms the true armature. The auxiliary nickel-silver strip projecting from the pole piece acts as a "stop spring," preventing excessive bending of the armature spring. The contact springs are actuated directly by the armature spring, and the contact openings, etc., may be varied by adjusting screws, which are provided with ebonite tips where they touch the springs.

These relays are rarely used except for the generation of trains of impulses, i e. repeated operation and release with definite time lags, and for this reason pendulum relays are often referred to as "vibratory relays." Another title in common use is "blobber relay"

The relay illustrated is arranged to operate on the trembler bell principle, one pair of contacts being used to short-circuit the coil when the armature spring is attracted. In other types the armature acts as a true pendulum, the steel spring being attracted to one side initially, then released,

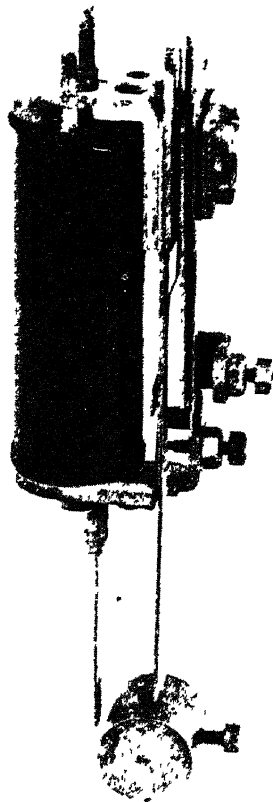


FIG 28. PENDULUM RELAY

after which the armature spring oscillates for about 5 seconds before the amplitude becomes too small to actuate the contacts. In general, a pendulum relay may be used where a complete cycle of operation and release is required with constant time lags, i.e. constant speed of impulsing; the individual lags of operation or release are dependent on contact openings, and, therefore, the ratio of make to break in the case of impulsing is affected by contact wear; it is also affected by the amplitude of vibration of the armature spring. The standard speed of impulsing is 10 impulses per second with a break period of 66.6 mS. and a make period of 33.3 mS.

Although not strictly pendulum relays, the vibratory relays used for generating tones are of the same class. The frequencies usually required are 133 or 400 cycles per second, and therefore the armature spring is shorter and stiffer, and has no additional weight or "bob." The travel is, of course, very small, and therefore it is not possible to actuate any contacts other than those which are designed for the trembler bell action. However, these contacts can be used quite satisfactorily for the dual purpose of self-drive and tone generation (See also "Voice Frequency Relays," later.)

Interlocking Relays.

Mechanical interlocking between relays is rare in automatic telephony, but the A.T.M. type of subscribers, "line" and "cut-off" relays described below is of importance, not only because of the interlocking but because the unusual type of construction has been retained by that manufacturer even when the interlocking facility has been omitted.

The cores and coils are of the same type as in the standard A.T.M. auto relay, but are slightly shorter. They are secured to a common iron back plate with the usual iron screw, but the armature in each case is at the side of the core in the position normally occupied by the yoke (Fig. 29). The "cut-off" relay, *K* (at the top), has its armature on the left-hand side, and the "line" relay, *L*, has its armature on the right. A "hinge" is formed at the heel end of each armature by two small lugs fitting loosely in holes in the back plate, and the parts are held together by a

spiral spring. The contact springs for both relays are mounted in one continuous line at the top of the assembly, and are actuated by long vertical projections at the forward ends of the armatures, the *K* relay contacts being operated from left to right, and the *L* relay contacts being operated in the reverse direction. Near the front ends of the springs is a slotted bridge-piece of ebonite, which provides buffers

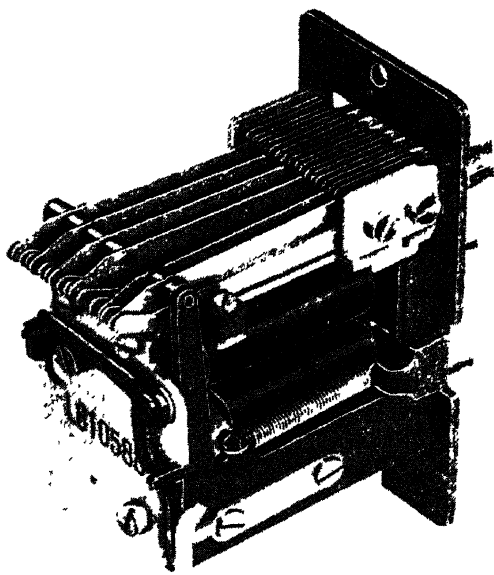


FIG. 29. INTERLOCKING RELAYS

for all make and break contacts. The large metal plate which covers the front ends of the cores is non-magnetic, serving merely as a mounting for the interlocking lever, but underneath this plate are pole pieces individual to each relay: the front plate is cut away to reveal the pole faces, so that the gap between pole and armature can be adjusted. The "residual" on the armature of the *L* relay is adjustable, consisting of a nickel-silver strip with a small bent "finger"

overlapping the end of the armature, so that it can strike the pole face and leave a residual air gap between armature and pole when in the operated position. This strip is secured to the armature by two screws, but as it is bent into a slightly concave form, the extent of the residual gap can be adjusted by tightening or loosening these screws. The residual gap on the *K* relay is fixed by a small brass pip riveted on the inner side of the armature.

The interlocking lever, or "latch," on the front plate engages with short lugs at the front ends of the armatures.

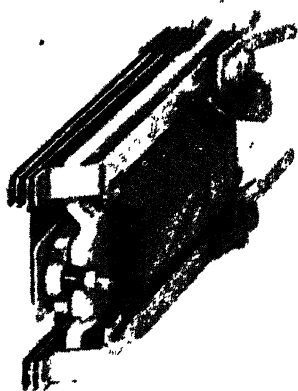


FIG 30 FLAT-TYPE RELAY

engages with short lugs at the front ends of the armatures. In the resting position as shown, it will prevent the full operation if the upper relay, *K* (the armature being on the left side), and the contact springs are adjusted so that in this half-operated position all break contacts are broken, but none of the make contacts are closed; this is a requirement of the A.T.M. subscribers' unselector circuit for non-director areas. If, however, the *K* relay is operated subsequently to the operation of *L*, then the latch is moved out of engagement by the *L* relay armature, and *K* can

operate fully without obstruction. As has been mentioned previously, this type of line and cut-off relay assembly may be used without the interlocking facility, in which case the only difference is the omission of the latch.

Flat Type Relays.

The normal A.T.M. and Siemens auto type relays, as described in Chapter I, have the same approximate dimensions, viz., $3\frac{1}{2}$ in. \times $1\frac{1}{4}$ in. \times 2 in. The flat type relay has been produced, not to provide any special facilities, but merely as a relay which would be economical in mounting space and in price, and yet have a performance suitable for modern telephone requirements. A representative example

is that manufactured by Standard Telephones & Cables, Ltd., and shown in Fig. 30; it is $3\frac{1}{2}$ in. \times $\frac{7}{8}$ in. \times $1\frac{3}{8}$ in.

It will be seen that the core is flat instead of round in cross-section, the armature consists of a U-shaped piece of metal hinged to the heel piece by means of a pair of flat springs. The great advantage of this method of construction is that each of the parts comprising the magnetic circuit is a simple pressing, thus reducing manufacturing costs in mass production, but it should be noted that a flat core is not so economical as a round section as regards the length of wire per turn of the winding. The armature travel is small, but the maximum sensitivity of the relay as a whole is limited by the small winding space available.

A.C. Relays.

The ordinary fast telephone relay will not remain rigidly operated when alternating current is passed through it, but will merely chatter in synchronism with the changes of current. It is frequently necessary, however, to have a relay which will operate when A.C. is passed through its coil at a frequency of 16 cycles per second (i.e. ringing current). A special relay for this purpose is that shown in Fig. 31. It is a gravity type relay with its coil mounted vertically; it has a single make contact actuated by an armature in the form of an inverted U, which is pivoted at the lower ends of the limbs. It will be seen that the upper portion of the armature moves at right angles to the axis of the core

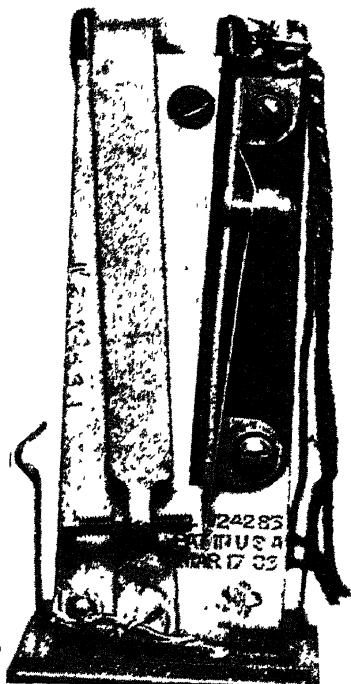


FIG. 31. A.C. RELAY

instead of along the axis, and by this means a long "travel" (nearly $\frac{1}{2}$ in.) can be obtained without an excessive air gap. Also, the mechanical inertia is so great that the armature cannot respond to the alternations of current and flux, with the result that a steady movement is assured. This inertia effect is quite different from that of slugs and sleeves, because, between the waves of current, inertia tends to keep the armature moving towards the pole face, whereas a slug merely delays the falling back. It should be noted also that, whereas the ringing trip relay (described previously) operates on D.C. but not on A.C., this A.C. relay will operate on D.C. or A.C. equally well. The time lags depend on circuit conditions and adjustment, but typical figures are 50 mS. for operation and 200 mS. for release.

The recent introduction of metal rectifiers has enabled standard A.T.M. type relays to be used for operation on alternating current, a small metal rectifier being mounted on the relay in the position normally occupied by one of the spring piles, and connected in parallel with the relay coil. This provides a shunt path for one half of the A.C. wave and, at the same time, the shunt makes the relay slow releasing during the period when the current is being diverted. Such a relay is much faster on normal operation and release than the type described previously.

Voice-frequency Relays.

Signalling with alternating currents at voice frequencies, i.e. 200 to 2,000 cycles per second, has recently been introduced into automatic telephony, and the specially tuned relays made by Standard Telephones & Cables, Ltd., for this purpose are of unusual design. The fundamental principle is the use of an extremely light and sensitive balanced armature coupled to a steel reed having a known frequency; the armature responds only to the correct frequency, and tuning facilities are provided. The field produced by the operating coils is augmented by a horse-shoe permanent magnet, as in a telephone receiver.

The "contact" of the relay is quite different from the normal type. A small ring of P.G.S. wire is fitted to the end of the reed, and a similar ring is mounted on the body of the relay; suspended between them is a small cylindrical

weight with hooks at each end, so that the contact assembly resembles a short length of chain with loosely fitting links. When the armature and reed vibrate in response to the correct frequency, this "chain" is disturbed, and an intermittent connection is produced in place of the steady contact. It is possible to use this chattering for controlling auxiliary relays direct, but an alternative arrangement is to treat the chattering as alternating current, and to operate an A.C. relay through a condenser.

Selector Magnets.

Although the electro-magnets used for stepping automatic telephone switches are designed primarily for the conversion of electrical energy into mechanical energy, the resultant motions are used for connecting the selector wipers to the bank contacts, and it has become necessary in a large number of cases to make the armature actuate electrical contacts in addition; thus they come into the category of relays. Moreover, their time lags are quite as important as those of other telephone relays. Fig 32 shows the construction of the three magnets used on two motion switches, called "selectors."

The vertical magnet (*VM*), which lifts the shaft to various levels, and the rotary magnet (*RM*), which rotates the shaft to various contacts, each have two 23 ohm coils in series, bridged at one end by a short iron strip or "yoke" and at the other end by the hinged armature. The actual hinge, however, takes no part in the magnetic circuit, as the flux passes through one coil and back through the other.

The release magnet, which swings the double dog (*DD*) out of engagement with the ratchets *VR* and *RR*, is an 83 ohm single coil magnet (100 ohms, shunted internally with a 500 ohm non-inductive spark quench resistance), with a separate yoke forming a return path for the flux to the armature. The armature hinge in this case is important magnetically, just as it is in ordinary telephone relays, and the rocker principle is used. There are two short lugs formed at the front end of the yoke to engage with holes in the armature, and these lugs prevent displacement of the assembly, besides improving the magnetic circuit as regards air gaps at the hinge.

The armature restoring springs and contact springs have been omitted from the illustration, but in practice the contacts are actuated by projections of the armature and are of the ordinary relay spring type, although usually somewhat stiffer to withstand vibration. Selector magnets are much more powerful than ordinary telephone relays, and,

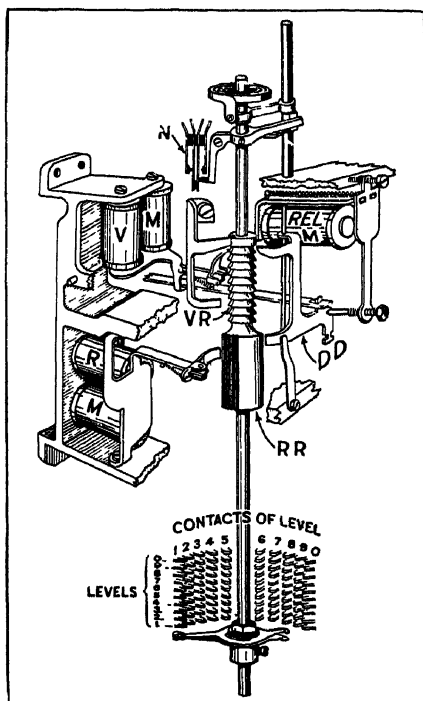


FIG. 32. SELECTOR MAGNETS

in order to obtain quick release, there is a special steel restoring spring, which exerts a force of about 1,000 grammes.

On group selectors the contacts on the rotary magnet are used to disconnect the magnet coil when operated, either directly or indirectly by means of an interacting relay. This produces a "trembler bell" action, causing the

wipers to "hunt" over the contacts; the standard speed of "stepping" in this way is 33 steps per second, whereas the normal speed of stepping by outside impulses is 10 steps per second. In any case it will be seen that fast operation and release are important.

The contact springs, *N*, are of the relay type and are operated mechanically by the raising of the shaft by the vertical magnet. They are restored by the lowering of the

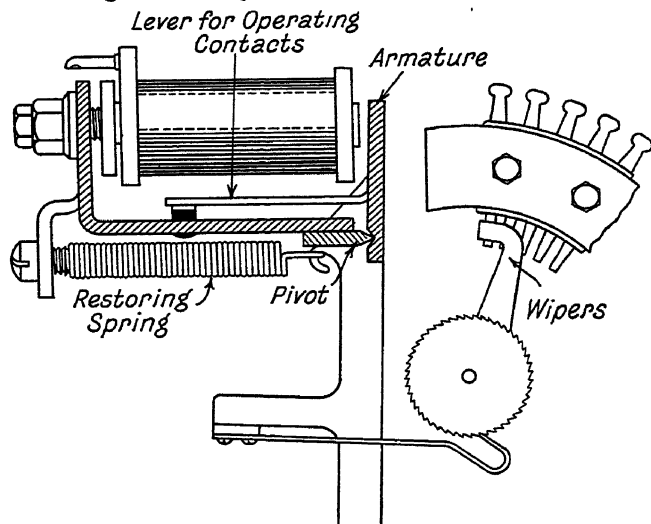


FIG. 33. UNISELECTOR MAGNET

shaft by means of the release magnet. They are termed "off-normal" springs, but the phrase implies the more exact title of "vertical off-normal" to distinguish them from "rotary off-normal" springs, *NR*, which are fitted in special cases. These latter springs remain unoperated during the vertical motion, but operate when the rotary magnet moves the shaft horizontally from the normal position. Thus the complete selector mechanism may be looked upon as one complex relay whose contacts are the off-normal contacts. Their time lags will be found in Appendix I, together with those of typical relays and magnets.

Another kind of selector contact is called the "Normal Post" assembly (abbr. *NP*), which is actuated when the shaft reaches certain levels, usually the first or second; in most cases the springs are restored when the particular level has been passed. In special cases other contact springs may be associated with the double dog.

A further type of selector magnet is that used in uniselectors,* or "rotary line switches," and the construction of the G.P.O. standard unselector is shown in Fig. 33. The armature is pivoted on a knife edge, and the contact springs (not shown) are used for breaking the circuit of the coil in order to cause hunting of the wipers over the bank contacts in the same way as in the case of the selector rotary magnet. This principle of operation is known as "self-interrupted drive," or, briefly, "self-drive," and the normal hunting speed of unselector magnets is 60 steps per second.

The representation of selector magnet contacts in G.P.O. schematic diagrams is slightly different from that of ordinary relay contacts, and this is shown in Fig. 9.

Dashpot Relays.

These are slow operating "plunger" or "solenoid" relays, a type which is not used in telephony except where a very long operating time is required, e.g. as a delayed alarm relay. The long stroke of the solenoid relay lends itself easily to the provision of an oil dashpot for the control of operating time, and the type made by the A.T.M. Co. is shown in Fig. 34. Its construction is simple, because

* B.E.S.A. term. See Appendix II.

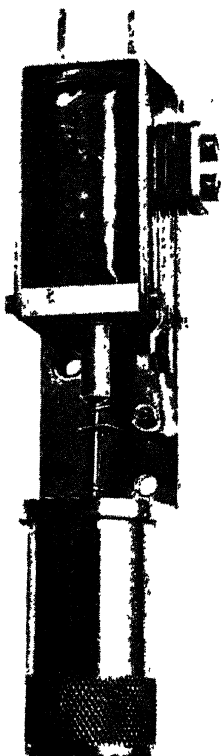


FIG. 34. DASHPOT RELAY

it has gravity control, and the plunger, which is drawn into the coil, is in line with the dashpot piston, loosely fitting universal joints being provided. Damping oil of various grades may be used in the dashpot itself to give the required time lag, but an additional adjustment is provided by a variable screw valve on the piston. The dashpot is not filled with oil completely, so that the final movement of the piston shall be speeded up, and the contacts shall be operated quickly and reliably. Quick release is obtained

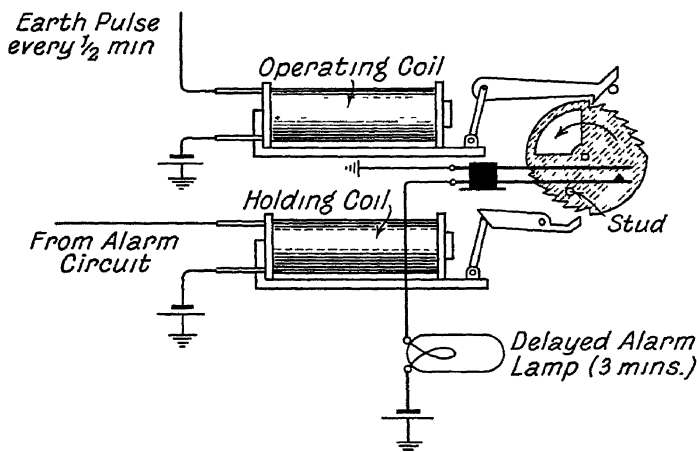


FIG. 35 RATCHET RELAY

by a one-way ball valve in the piston. The contacts are of the normal relay type and are operated when the collar on the piston rod rises sufficiently to actuate the bell-crank lever, a time lag of 3 minutes being a typical adjustment.

Ratchet Relays.

An alternative type of relay with very long operating lag is the "Ratchet" or "Time Check" relay, shown in diagrammatic form in Fig 35. Its operating time is controlled by earth pulses supplied by a clock, and it therefore gives more stable timing than the dashpot. It consists of two coils side by side, one of which, the "operating coil,"

is operated every $\frac{1}{2}$ minute by the clock. The armature associated with this coil is connected to a ratchet, which engages with the upper teeth of a ratchet wheel. Under normal conditions, however, this wheel is never stepped beyond the "first tooth" position because it falls back after each operation, being unbalanced. If, however, the holding coil is energized by the operation of some distant alarm circuit, a holding ratchet is allowed to engage with the teeth on the lower edge of the wheel. Thus at each subsequent movement of the operating coil the ratchet wheel is no longer permitted to drop back to the normal position, and it is rotated tooth by tooth until, when the sixth earth pulse arrives, i.e. after 3 minutes, a stud on the wheel engages with a pair of contact springs, which connect up an alarm lamp or other supervisory circuit. When the earth from the alarm circuit is removed, whether before or after the 3 minutes has elapsed, the holding ratchet is disengaged and the ratchet wheel promptly restores to normal, thus fulfilling the requirements of quick release

Telegraph Relays.

The relays normally used for telegraph purposes are sometimes employed in special testing apparatus in automatic telephony because they have been designed specially for fast operation regardless of bulk. The relay most often used for this purpose is the G.P.O. "Standard B" relay, which is a double-pole polarized relay with one break-make assembly. The construction is unique in having two armatures on the same spindle, one at each end of the coil, as shown in Fig. 36. Each armature is in the form of a short flag which can move over to the pole piece of one or other coil. The upper armature is always a magnetic N. pole and the lower armature a S. pole, owing to the proximity of the poles of a permanent horse-shoe magnet, this magnet being bent into a curious shape for convenience in mounting. Thus the direction of movement of the armatures is dependent on the polarity of the electro-magnets. Two windings of equal resistance are usually provided, each having half of its turns in one coil and half in the other.

The make and break contacts are mounted rigidly to the top plate of the relay case, and the moving contact is

fastened directly to a brass tongue on the armature spindle. When in the resting position a restoring force or "bias" in either direction may be provided at any strength by moving the armature nearer to one coil than the other, and an adjusting screw (not shown) is provided for this purpose. In this way the relay can be made extremely sensitive,

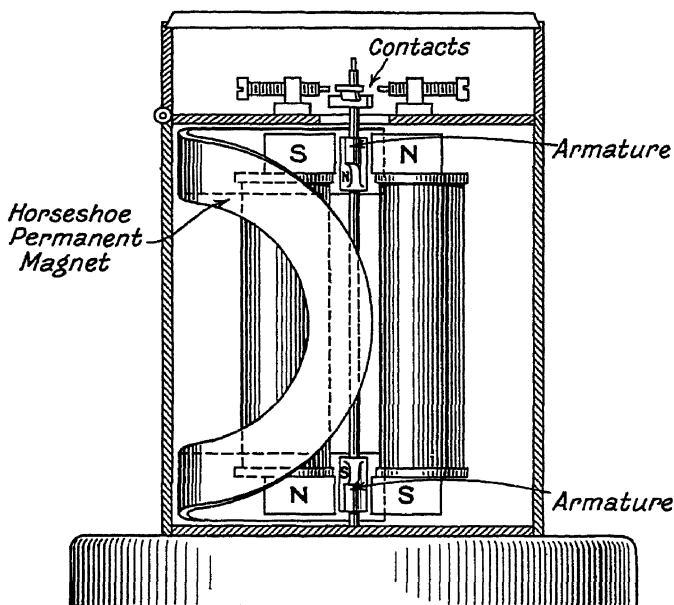


FIG. 36 TELEGRAPH RELAY (POLARIZED)
Explanatory sketch.

and, as the rigid contacts allow a very small travel to be used, the operating time can be reduced to 1 millisecond with ease. As a rule, the contacts are not designed to carry heavy currents or withstand high voltages.

The "Standard B" relay is enclosed in a brass case for bench mounting, a hinged glass cover being provided for inspection of the contacts, and electrical connection to coils and contacts is obtained by screw terminals on the wood base plate.

Motor Start Relays.

Relays for starting and stopping fractional horse-power motors at voltages up to 250 require a special construction in view of the possibility of arcing at the contacts.

An example of a motor start relay of the solenoid type, as manufactured by Messrs. Power Equipment Co , Ltd , is

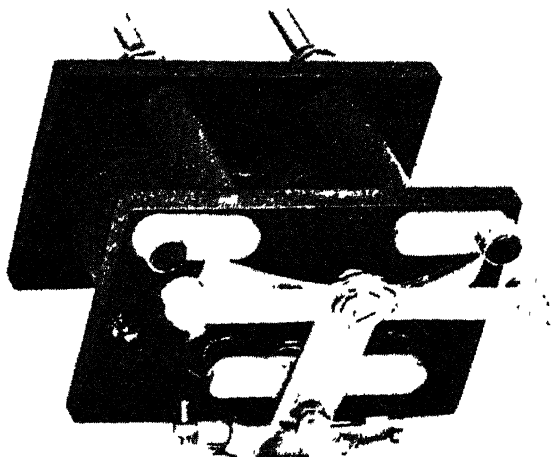


FIG. 37. MOTOR START RELAY (SOLENOID)

shown in Fig. 37, the overall dimensions, excluding terminal screws at the back, being $3\frac{1}{2}$ in. \times $2\frac{1}{2}$ in. \times $3\frac{1}{2}$ in. The plates seen at the back and at the front are of ebonite and are for mounting only. Between them are two coils side by side, the ends of the cores being bridged at the back by a short fixed yoke and at the front by the armature. The armature is mounted on a hinged strip, which also carries the moving contacts, the contact assembly is of the single pole double-break type, as on an ordinary tumbler switch, having two fixed electrodes and a movable bridge which connects them. In addition to the main bridge, consisting of a laminated phosphor-bronze spring engaging with brass contacts, there is also provided an

SPECIAL RELAYS

auxiliary bridge terminating in carbon contacts mounted in metal cups. These auxiliary contacts break last during the release motion and take the arcing, which constitutes the principle source of wear. Facilities are provided for renewing these contacts quickly and cheaply, but it is estimated that they will break 1 ampere in a motor circuit at 250 volts for at least 100,000 operations before renewal

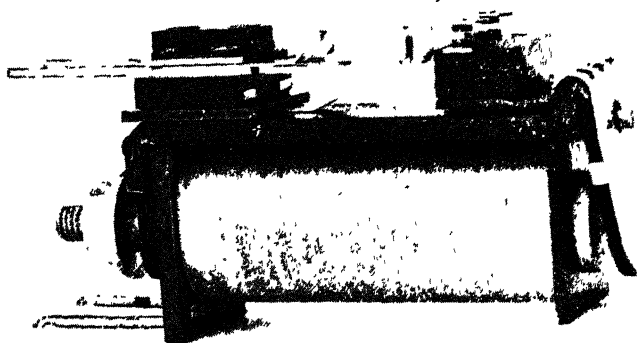
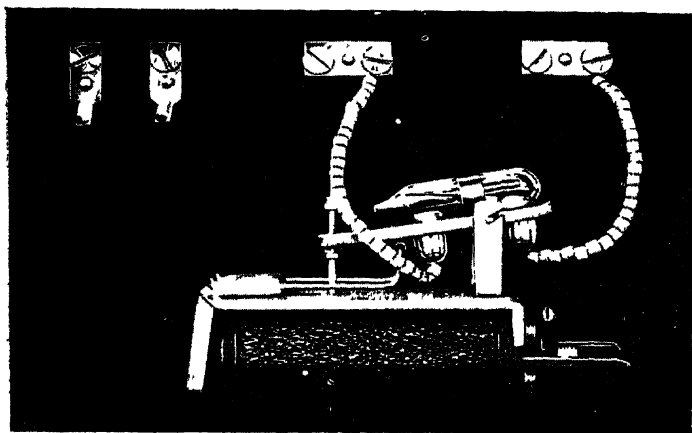


FIG 38 MOTOR START RELAY (TELEPHONE TYPE)

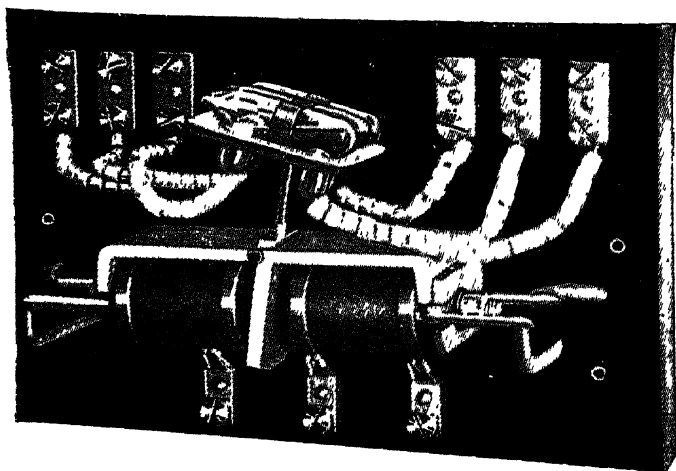
will be required. As regards sensitivity, a representative example is the 400 ohm relay which operates at 75 mA.

For lighter current loads at high voltage, the magnetic circuit of the ordinary telephone relay may be used, provided that a special design of contact is employed. The relay illustrated in Fig 38 is that manufactured by Messrs. Siemens Bros. & Co., Ltd. It is suitable for signalling purposes in automatic sub-stations, and has all the good characteristics of a telephone relay as regards speed of operation, compactness, etc. The contacts are of tungsten and the insulation of the contact springs is designed to withstand 200 volts.

For voltages higher than this (up to 1,000) mercury contacts may be substituted, and two examples of this type of relay made by Isenthal & Co., Ltd., are shown in Fig. 39. The mercury is in a sealed glass tube containing a



(a) Normal type



(Isenthal & Co Ltd)

(b) For push-button control

FIG 39 MERCURY CONTACT RELAYS

non-oxydizing gas, thus avoiding failure of the contacts. The example at (a) has a magnetic circuit of the ordinary telephone type, with one make contact capable of carrying 2 amperes, but larger mercury tubes may be obtained for carrying currents up to 10 amperes. Other tubes have three contact points, thus giving a break-make action. The relay shown at (b) has three tubes with single make contacts, but is also unique in being suitable for push-button control. Two separate opposing coils are used with a common armature, which can be attracted to either by a pulse of current in one coil. Whichever way the armature is tilted, it remains in that position until moved by a pulse of current in the opposite coil, thus effecting an economy in power consumption.

Moving Coil Relays.

Such relays are really adaptations of moving coil milliammeters, contacts being placed at either side of the pointer and the scale removed. A relay of this type is made by the Weston Electrical Instrument Co., Ltd. The position of the make and break contacts may be adjusted so that the travel of the pointer (i.e. moving contact) is from $\frac{1}{10}$ to 5 millimeters. Great sensitivity is thus obtained, and with a 500 ohm coil and a contact travel of 1 mm. the relay will operate on 0.02 mA. With such sensitivity, no attempt is made to carry large currents at the contacts and a maximum of 200 mA. at 6 volts is specified. The question of critical damping must be considered in the same way as with milliammeters if a firm contact is to be assured.

Thermostat Relays.

These relays, as their name implies, are not electromagnetic but depend on heating characteristics. They are manufactured by the Relay Automatic Telephone Co., Ltd., and are used in their private branch exchange equipment as delayed alarm relays. It will be seen from Fig 40 that a small coil of wire is wound on the moving spring of a break-make contact assembly suitable for mounting on standard R.A.T. Co.'s relays, the terminations being taken to the soldering tags included in the spring pile. It should be noted, however, that the illustration shows the relay in

the unoperated position, the direction of motion being downwards, the reverse of normal relay spring operation. The moving spring is bi-metallic, consisting of a strip of iron and a strip of brass welded together by a special process. Alternatively invar and brass has been used. The coefficient of linear expansion of iron is approximately 11×10^{-6} per $^{\circ}\text{C}$. rise in temperature, and that of brass is approximately 19×10^{-6} per $^{\circ}\text{C}$., so that if the brass strip is uppermost and the composite spring is heated by means of the coil of wire round it, the temperature being proportional to the resistance and the square of the current, the

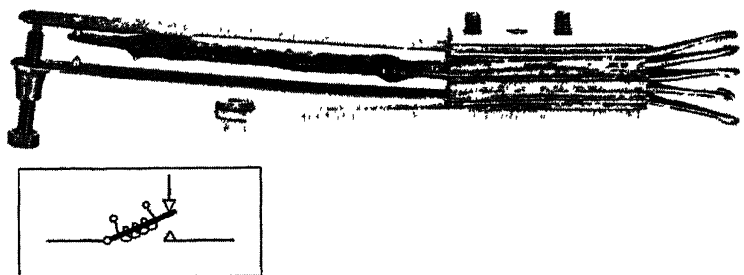


FIG. 40 THERMOSTAT RELAY

different expansions will cause the spring to bend downwards, leaving the break spring and making contact with the make. Follow of the break contact is prevented by an insulated screw separating the make and break springs.

In practice, all three springs are bi-metallic, with the result that any changes in the normal atmospheric temperature produce bending of the whole assembly and do not cause false operation. Thermostats can be made to operate in from 15 seconds to 2 minutes, subject to variations due to battery voltage or residual heating from previous operation. This range is achieved largely by adjustment of spring pressure and contact opening, since working temperature is limited by the fire risk. The figures given refer to the operating time measured at the make contact, but about 40 per cent of this lag is occupied in "transit

time" between break and make. The normal resistance of a thermostat for working on a 24 volt battery supply is 100 ohms, this being the limit of resistance which can be wound satisfactorily on the standard size of spring. Releasing time is dependent on the duration of previous heating and is difficult to define, but is of the order of 1 minute. Owing to this slow release, the thermostat has a more limited application than the dashpot or the ratchet relays.

The conventional method of representing thermostat relays on circuit diagrams is shown in the inset of Fig. 40.

CHAPTER VI

RELAY DESIGN

Introduction.

THE manufacture of telephone relays is carried out on such a large scale, and with so few main types of magnetic circuit, that design has become a matter of routine rather than of elaborate fundamental calculation. The purpose of this chapter, however, is not to give a list of the data required for the design of any particular type of relay, but to show how this data may be collected and utilized in a convenient form, and how special circuit conditions must be considered. Moreover, it falls to the lot of the relay designer to decide what current adjustments shall be specified, and, therefore, the method of compiling adjustment charts is also dealt with.

Magnetic Circuit.

The primary function of the magnetic circuit is the efficient conversion of magnetic force into flux, and the relationship between the two is expressed by an equation which is similar to the well-known Ohm's Law, " $E = IR$," for electrical circuits, viz.—

$$\mathcal{E} = \Phi S \quad \text{where} \quad \begin{cases} \mathcal{E} = \text{magnetic force} \\ \Phi = \text{flux} \\ S = \text{reluctance} \end{cases}$$

$$\text{but } \mathcal{E} = Hl \quad \text{where} \quad \begin{cases} H = \text{magnetic field} \\ l = \text{length of magnetic circuit} \end{cases}$$

$$\text{and } S = \frac{l}{a} \times \frac{1}{\mu} \quad \text{where} \quad \begin{cases} a = \text{cross-sectional area} \\ \mu = \text{permeability} \end{cases}$$

$$\begin{aligned} \therefore Hl &= \Phi \times \frac{l}{a} \times \frac{1}{\mu} \\ &= \frac{\Phi}{a} \times \frac{l}{\mu} \end{aligned}$$

$$\therefore H = B \times \frac{1}{\mu} \quad \text{where} \quad B = \text{flux density}$$

Since μ , the permeability, varies with different values of B and with different magnetic materials, this relationship is usually shown graphically in the form of a B/H curve for each material. It is more convenient for relay work, however, to express the relationship between the flux density B and the ampere-turns applied to the winding of a given type of relay, the number of A.T. being equal to $0.8 Hl$

A flux/ampere-turns curve can be constructed from first principles if the relationship between ampere-turns and flux

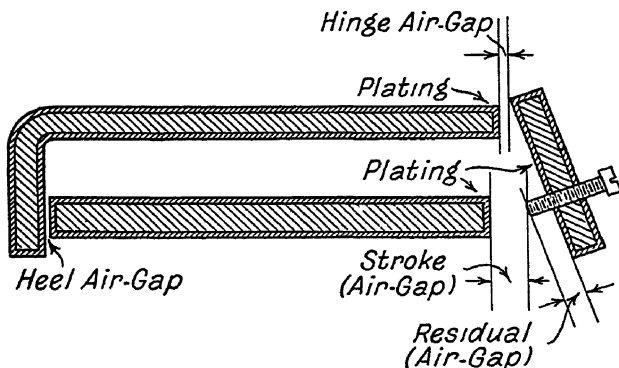


FIG 41. REAL AND VIRTUAL AIR GAPS

is considered for each portion of the magnetic circuit:—core, heel piece, yoke, and armature, together with the various air gaps, and not forgetting the virtual air gap introduced by the plated surfaces between core and heel piece (Fig. 41). In practice, the dimensions of the magnetic circuit are, with the exception of the residual air gap, fixed for any given type of relay, and therefore a curve for each type can be constructed showing directly the relationship between ampere-turns and total flux. Fig. 42 shows a series of such curves for the A.T.M. type, a number of curves being necessary because of the one variable, the air gap between armature and core (stroke + residual + plated surfaces). In the construction of such curves the effect of “fringing out” of the flux at the air gaps should be considered.

Basic Ampere-turns.

The main controlling factor in the design of the winding for a given relay is the downward pressure which will be exerted on the armature by the spring assembly. This force, known as the "load," must be overcome by a certain flux, which in turn must be produced by a certain number of ampere-turns. Fortunately, almost every relay operates when the flux is still below saturation, and, therefore, for a given armature air-gap (normally about 20 mils) the number of ampere-turns is directly proportional to the flux (Fig. 42). All that is necessary, therefore, is to express

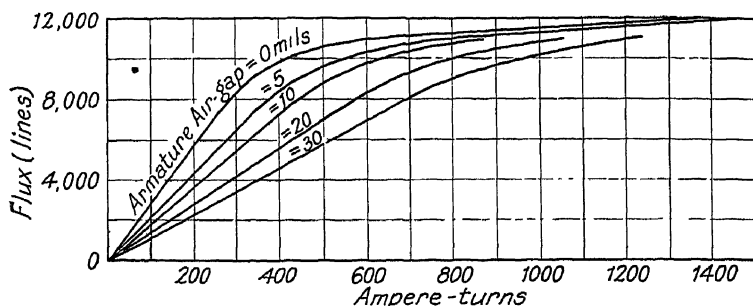


FIG. 42. FLUX/AMPERE-TURN CURVES

the direct relationship between the load exerted by the contact springs and the ampere-turns required to operate them, this number of A.T. being called the "basic operating adjustment," or "basic operate ampere-turns."

It is well known that the tractive force of an electro-magnet is—

$$\frac{B^2 a}{8\pi}$$

where a = area of contact between armature and pole face.

When there is an armature air gap the formula is modified considerably, but the force is still proportional to the square of the flux. Thus the basic operating adjustment

can be expressed as follows. (These figures apply to the A T M relay.)

Effective Spring Combination	Basic Operating Adjustment
<i>x</i> Operation—	
Makes	100 $\sqrt[3]{n}$ A T.
Breaks	180 $\sqrt[3]{n}$ A T.
<i>Full Operation</i> —	
Moving springs	90 $\sqrt[3]{n}$ A T
(or) Breaks	120 $\sqrt[3]{n}$ A.T.

n = number of springs of each type

With regard to the second section in the above table, alternative figures are given, one for moving springs irrespective of making or breaking functions and one for break contact springs only. Every moving spring must have a certain minimum tension, from considerations of rigidity of the complete assembly and absence of spring vibration, but those associated with break contacts must have a higher minimum tension in order to provide a sufficient break contact pressure, and if the proportion of breaks in the assembly is below a certain value this new minimum will be greater than the previous one.

Thus, for a mixed spring assembly of makes, breaks, and break-makes, both calculations will be made and the larger number of ampere-turns will be taken as the basic adjustment. The ampere-turns calculated on the two schemes for the same contact assembly are never added together.

EXAMPLE.

Determine the basic operate ampere-turns for an A.T.M. relay with the following spring assembly (relay *HS* in Fig. 45)—

Upper spring pile $x \cdot M \cdot B \cdot BM \cdot M$
 Lower spring pile $B \cdot BM \cdot MbB$

SOLUTION.

x operation—A.T. required for 1 *x* make contact == 100*Full* operation—

A T. required for the 7 moving springs = $90\sqrt{7}$
 == 238 A.T.

or A.T. required for the 5 break springs = $120\sqrt{5}$
 == 268 A.T.

The latter figure is adopted, being the greater.

ANSWER.

x operation . . . 100 ampere-turns.

Full operation . . . 270 ampere-turns.

These A.T. figures represent an average adjustment, and in cases where a specially light or specially heavy spring pressure is required, such as for the control of time lags, the basic values may be varied considerably.

There may be other factors modifying the basic operating adjustment, predominance of MbB contacts, flux leakage in the case of slugged relays, non-standard gauging, class 3 spring thickness instead of class 1, etc., etc. Each may have an effect of the order of 10 per cent, the exact figures being determined usually by experiment. The effect of variation of spring thickness is considerable, since the tension for a given deflection is proportional to the cube of the thickness, and therefore it will be observed that variations in the sheets of metal used for the springs will have a very marked effect on adjustments.

Siemens relays are calculated somewhat differently, the loads for each separate spring assembly, make, break, MbB, etc., being added together. Reference is then made to a graph which shows the relationship between total load and operate ampere-turns required. The results are of the same order of magnitude as for A.T.M. relays.

Basic release ampere-turns are also used occasionally, although it is more usual to determine the release current with reference to the circuit requirements. In other cases,

the relay is required to release only on disconnection of the coil circuit

Coil Design.

Having obtained the number of ampere-turns required, the next step in the design of a relay is the determination of the gauge of wire to be used. It is therefore necessary to know the relationship between the resistance of the winding (determining the current which will flow) and the number of turns.

The resistance is directly proportional to the length of the wire in the winding and the specific resistance of the

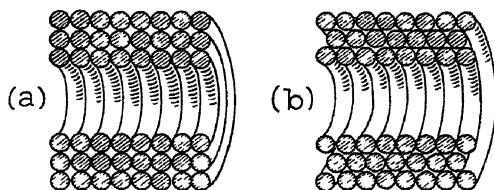


FIG 43 BEDDING OF WIRES

copper, and is inversely proportional to the cross-sectional area of the wire. This might be expressed as—

$$R = \rho \frac{L}{a}$$

where R = resistance of coil

ρ = specific resistance

L = length of wire

a = area of wire

or

$$R = \rho \frac{Tl}{\frac{\pi}{4} d^2}$$

where T = number of turns

l = average length per turn

d = diameter of wire.

For the purpose of this calculation d is taken as the diameter of "wire plus insulation," and the cross-sectional area occupied by the wire is assumed to be a square with

sides equal to d , since the layers are imagined to be lying evenly, as shown in Fig. 43 (a). In practice, of course, the waste space in the middle of each set of four wires is filled up to some extent by the wires bedding down as shown at (b), especially in the case of fine wires, but, as an approximate relationship it may be taken that

$$d^2 = \frac{A}{4}$$

where A = cross-sectional area of winding
so that—

$$R = \rho \frac{T^2 l}{\frac{\pi}{4} A}$$

From this it is seen that the resistance of a fully wound coil should be proportional to the square of the turns, if all the remaining variables, specific resistance, average length of wire per turn, and cross-sectional area of the winding, i.e. winding space, are constant for a given relay. Some correction must be made, however, for the space occupied by the insulation of the wire, but this is a case for experimental determination.

To facilitate design it is best to use a graph of winding data, which shows not only the relationship between resistance and turns, but also the wire gauge (bare) and overall diameter of the coil. An abridged reproduction of a graph for A.T.M. relays is shown in Fig. 44. Both resistance and turns are expressed as “per 1 inch winding space length” in order to cater for slugged relays in which part of the normal winding space length is occupied by the slug. The dotted curves showing overall diameter are necessary when dealing with two windings on the same core. The use of this winding data is best illustrated by examples of relay calculations

EXAMPLE (A).

A coil is required for a fast relay with a spring set demanding a basic operating adjustment of 270 A.T., a factor of safety of about 2.5 is desired when the relay is

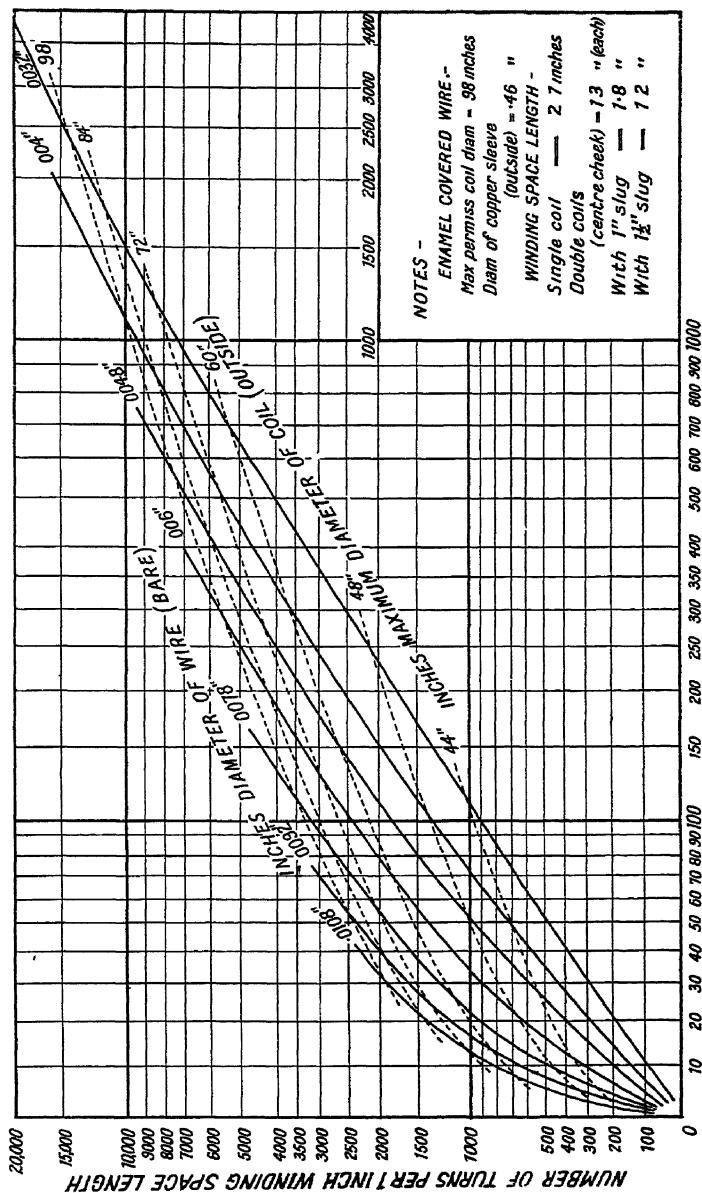


FIG. 44. WINDING DATA FOR A.T.M. RELAYS

operated by a 50 volt battery, and the resistance of the coil should be as high as possible. Determine the following—

- (a) Size of wire.
- (b) Resistance of wire.
- (c) Number of turns.
- (d) Current received at 50 volts.
- (e) Basic operate current.
- (f) Actual factor of safety.

Make an estimate of the resistance, say 1,000 ohms, and determine by a rough calculation whether this would produce a suitable relay—

$$\text{Current received at 50 volts} = \frac{50 \text{ V.}}{1000} = 0.05 \text{ amp.}$$

$$\begin{aligned} \text{Total number of ampere-turns required} &= 270 \text{ A.T.} \times 2.5 \text{ (F S)} \\ &= 700 \text{ A.T. (approx.)} \end{aligned}$$

$$\text{Total number of turns required} = \frac{700 \text{ A.T.}}{0.05 \text{ A.}} = 14,000 \text{ turns}$$

(Winding space length is given as 2.7 in.)

$$\begin{aligned} \therefore \text{Turns per inch winding} &= \frac{14000 \text{ T}}{2.7 \text{ in}} \\ \text{space length} &= 5,000 \text{ T/in (approx.)} \end{aligned}$$

$$\begin{aligned} \text{Resistance per inch winding} &= \frac{1000 \Omega}{2.7 \text{ in}} \\ \text{space length} &= 400 \Omega/\text{in. (approx.)} \end{aligned}$$

The graph of winding data at 400 $\Omega/\text{in.}$ and 5,000 T/in shows that such a relay would not be fully wound, the overall diameter of the coil being 0.72 in. instead of the full diameter of 0.98 in. It follows, therefore, that a coil resistance greater than 400 $\Omega/\text{in.}$ can be tolerated, and it is noted that the nearest fully-wound relay with a higher resistance is that wound with 0.0048 in. wire, corresponding to about 550 $\Omega/\text{in.}$ (i.e. total resistance approximately 1,500 ohms).

Re-calculate, therefore, for a 1,500 ohm coil—

$$\begin{aligned} \text{Resistance per inch winding} &= 1500 \Omega \\ \text{space length} &= 2.7 \text{ in.} \\ &= 555 \Omega/\text{in. (exact)} \end{aligned}$$

On the graph, $555\Omega/\text{in.}$ and 0.0048 in. wire correspond to 7,400 turns per inch.

$$\begin{aligned}\therefore \text{Total number of turns} &= 7,400 T/\text{in} \times 2.7 \text{ in.} \\ &= 20,000 T\end{aligned}$$

$$\text{Current received at 50 volts} = \frac{50 \text{ V.}}{1500\Omega} = 0.0333 \text{ amp.}$$

$$\begin{aligned}\text{Ampere-turns provided} &= 0.0333 \text{ A} \times 20,000 T \\ &= 666 \text{ A.T.}\end{aligned}$$

$$\text{Basic ampere-turns required} = 270 \text{ A.T.}$$

$$\therefore \text{Actual factor of safety} = \frac{666}{270} = 2.47$$

(This is sufficiently near to the 2.5 specified.)

$$\text{Basic operate current} = \frac{270 \text{ A.T.}}{20000 T} = 13.5 \text{ mA.}$$

ANSWER.

Size of wire	= 0.0048 in diam (bare)
Resistance	= 1,500 ohms
Number of turns	= 20,000
Current received	= 33.3 mA
Basic operate current	= 13.5 mA
Factor of safety	= 2.47

EXAMPLE (B).

If the above coil were divided into two separate windings, and the inner winding were to have a resistance of 200 ohms, what would be the basic x operate current for this winding? (The basic operating adjustment for 1 x make is 100 A.T.) Neglect the thickness of insulation between the two windings

For the inner winding—

$$\begin{aligned}\text{Resistance per inch winding} &= \frac{200\Omega}{2.7 \text{ in.}} \\ \text{space length} &= 74\Omega/\text{in.}\end{aligned}$$

From the graph of winding data it is seen that $74\Omega/\text{in.}$ and 0.0048 in. wire corresponds to 1,400 turns per inch.

$$\begin{aligned}\therefore \text{Total number of turns in} \\ \text{the 200 ohm winding} &= 1,400 \text{ T/in.} \times 2.7 \text{ in} \\ &= 3,800\end{aligned}$$

$$\therefore \text{Basic } x \text{ operate current} = \frac{100 \text{ A T}}{3800 \text{ T}} = 26 \text{ mA}$$

ANSWER

$$\text{Basic } x \text{ operate current,} \quad = 26 \text{ mA}$$

EXAMPLE (C).

If, in Example (B), the 200 ohm winding for x operation were the outer winding instead of the inner, what would be the basic x operate current then?

The graph refers only to inner windings, i.e. those wound directly on the core, so it is not possible to determine the number of turns in the outer winding until the number in the inner winding is known.

For the inner winding—

$$\begin{aligned}\text{Total resistance} &= 1500 - 200 = 1300\Omega \\ \text{Resistance per inch winding} &= \frac{1300\Omega}{2.7 \text{ in}} \\ \text{space length} &= 482\Omega/\text{in}\end{aligned}$$

From the winding data it is seen that $482\Omega/\text{in}$ and 0.0048 in wire corresponds to 6,700 turns per inch

$$\begin{aligned}\therefore \text{Total number of turns in} \\ \text{the 1,300 ohm winding} &= 6,700 \text{ T/in} \times 2.7 \text{ in} \\ &= 18,100\end{aligned}$$

$$\begin{aligned}\text{But total number of turns in} \\ \text{the complete coil} &= 20,000\end{aligned}$$

$$\begin{aligned}\therefore \text{Number of turns in the 200} \\ \text{ohm outer winding} &= 1,900 \\ \therefore \text{Basic } x \text{ operate current} &= \frac{100 \text{ A T.}}{1900 \text{ T.}} \\ &= 53 \text{ mA}\end{aligned}$$

ANSWER

$$\text{Basic } x \text{ operate current} \quad = 53 \text{ mA.}$$

For certain circuit conditions, an "exact turn" winding may be specified, in which case the resistance is kept within

the specified limits (± 5 per cent) by the use of nickel silver resistance wire where necessary.

Adjustment Charts.

In a previous paragraph it was shown how to obtain the basic operate ampere-turns for a given relay, but even

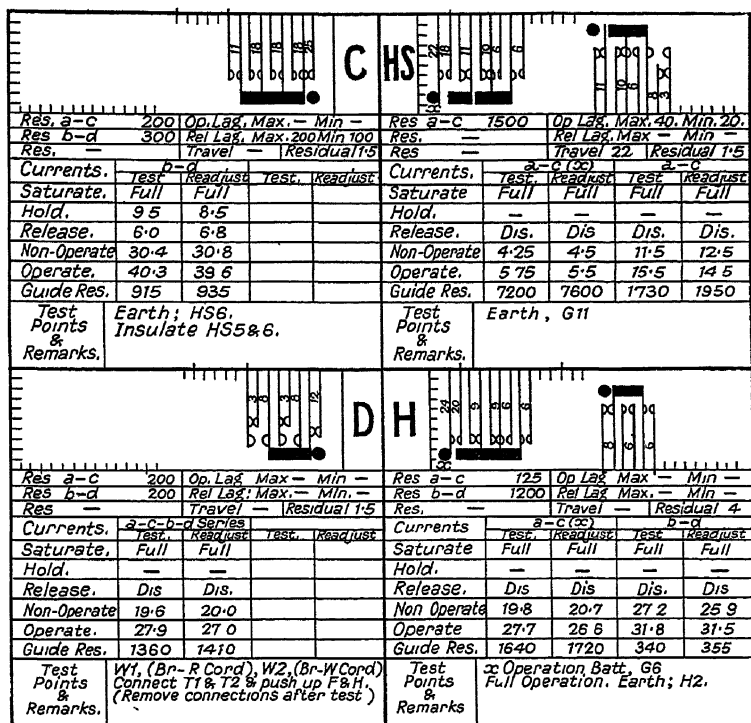


FIG 45. ADJUSTMENT CHART OF TYPICAL A T M RELAYS

when this is converted into a "basic operate current" by dividing by the number of turns in the winding, it does not represent a complete "adjustment," such as will be required for maintenance. The adjustment chart is, therefore, an important part of the relay design. A typical adjustment chart for an imaginary relay set consisting of four relays

is shown in Fig. 45. The relay code letters shown in one corner of each section are the letters by which the relays are identified in the circuits. Where relays are mounted in pairs (Fig. 8), they are arranged on the chart in the order in which they are mounted on the relay plate. Where relays are not mounted in pairs, they are arranged alphabetically on the chart in accordance with their code letters.

The method of showing the adjustment of the spring assembly has been dealt with in Chapter III. Similarly, the entries for "travel" and "residual" require no further remarks except that the unit used is "mils."

The various current and time tests are carried out in the following order—

- Saturate current.
- Hold current (if specified).
- Release current.
- Non-operate current (if specified).
- Operate current
- Operating lag } (if specified).
- Releasing lag }

Some of the adjustments are specified only in cases where special circuit conditions demand them. Any other special adjustments are entered in the "Remarks" space. The letters *a-c*, *b-d*, etc., at the heads of the current columns denote the tags of the coils to which the adjustments refer. If an *x* is inserted also at the head of the column, the adjustments which follow refer to *x* operation only. The resistances of the coils *a-c* or *b-d* are expressed in ohms, currents in milliamperes (mA.), and time lags in milliseconds (mS.).

Saturate Current.

This is not an "adjustment" in its real sense, but is merely a minimum current which is to be applied to the relay coil before the remaining current tests are applied. The saturate current is intended to saturate the core magnetically, but where this condition is not reached during normal functioning, the "saturate current" specified is really the normal working current. Provided that the winding would not be damaged by connection to the full P.D.

of the battery, i.e. is "self-protecting." this voltage is applied and the saturate current is specified as "full."

If the saturate current test were not used, there would be no guarantee that relays were in the same condition as regards residual magnetism when the subsequent tests were made, and although this scheme of tests is not so severe from the point of view of minimum operate current as the scheme of demagnetizing before each current test, it is much more easily carried out under maintenance conditions. It is most important to remember that the adjustment chart is designed to give figures which will enable all relays of the same type to have a uniform adjustment, and that these figures do not necessarily indicate the limiting circuit conditions. Moreover, the effects of saturation will last for a considerable time, certainly for the duration of the adjustment of the relay, whereas demagnetization must be repeated before each test

The difference between operate currents measured after saturation and after demagnetization is of the order of 5 per cent.

Hold Current.

This is the minimum current which will retain the armature in its operated position when the current is reduced in one step from the saturate value. An alternative method of testing a hold current is to reduce the current gradually from "saturate" to "hold," and this gives a slightly different adjustment. The reduction of current in one step is easier to carry out during routine tests. Another alternative is to specify the reduction of current from the operate value instead of from the saturate value, and this gives a hold current which is 10-20 per cent lower. For reasons already stated, however, it is desirable to use the saturate current as a basis for all tests.

Release Current.

This may be described as a non-hold current, since hold and release currents may be considered together to form a working tolerance, in the same way as operate and non-operate currents. The release current is defined generally as the maximum current which will permit all contacts to

restore to normal when the current is reduced in one step from the hold value (or, if no hold current is specified, from the saturate value). When it is necessary only that the relay shall release on disconnection, the hold current is omitted and the abbreviation "dis." is entered in the release current space on the chart to indicate that the circuit should be disconnected.

Non-operate Current.

In its fundamental sense, this is the maximum current which, when applied to a relay after previous saturation and release, will not open any break contact or close any make contact. This is the definition from the point of view of circuit operation, but, as has been explained previously (page 45), one or two of the first break contacts in a large spring pile of the A.T.M. type may be allowed to break during the non-operate test, in order to check the break contact pressure. Where one adjustment is given for x operation, and a separate current is given for full operation of the complete spring pile, the x contacts are always permitted to function on the non-operate current for the full spring pile.

Operate Current.

This is the final current test and is usually the most important from the circuit point of view. It is defined generally as the minimum current which, when applied to a relay after saturation, will open every break contact and close every make contact to which it refers. The contact travel must be completed within a reasonable time for the type of relay referred to, and the armature (or its residual screw) must touch the core, unless otherwise specified, e.g. x operation only. In some cases this latter requirement is waived, and the test is then referred to as a "touch-operate" current, since the make contacts need only "touch."

Test and Readjust Values.

The values of operate and non-operate current represent a tolerance on the basic operate current. Two tolerances

are usually specified, giving rise to "test" values and "readjust" values on the adjustment chart.

The test currents represent the safe limits, or tolerances, of adjustment both on operation and release, within which reliable functioning of the relay is guaranteed, and are used when checking adjustments. A relay is not readjusted unless its adjustment is outside the range of these values.

The readjust currents should provide the most accurate adjustment that can be obtained under practical conditions, and relays are readjusted to these values when found faulty. For most A.T.M. relays the test operate and non-operate currents are approximately ± 15 per cent on the basic operate current and the corresponding readjust currents are ± 10 per cent. When MbB contacts are employed it is not possible to keep the tolerances as low as this, and the figures for "test" and "readjust" are increased to ± 20 per cent and ± 15 per cent respectively.

The hold and release currents may be obtained in a similar manner from a basic release adjustment, but as a rule the test and readjust values are usually decided by experiment for the particular cases, with due regard to the circuit requirements

Test Points and Guide Resistance.

Though not strictly part of a relay design, these entries on the adjustment chart may be considered at this point most conveniently. The "test points" are the tags, relay springs, etc., in a complete relay set or selector to which a milliammeter and resistance may be connected most easily for testing the current adjustment of the relay. As a rule, it is more difficult to make connection to a coil tag at the back of a relay set which is mounted on a rack than it is to tap on a relay spring which is accessible from the front, even if that spring is on another relay. It does not matter if the circuit between the coil tag and the test point is via other break contacts, so long as such contacts are not operated during the test, if make contacts are in series it is necessary to give instructions for the wedging of the associated relays in the operated position. Besides relay contacts, there are other convenient test points, such as test jack springs, magnet coils (which have exposed

terminals), selector wipers, etc. In some cases the break contacts on other relays must be separated by an insulating wedge in order to isolate the circuit of the relay under test and prevent parallel circuits: all such information is given in the remarks space. The test points for the milliammeter are given in the form "Earth: G11," which would mean that the meter should be earthed on one side, and the other side be connected to contact spring number 11 on relay *G*. It may be assumed, therefore, that contact G11 is connected directly to one side of the relay winding under test and that the other side of the winding is connected to battery, thus completing the testing circuit.

The "guide resistances" are the values of resistance which, when inserted in series with the relay windings, via the specified test points, will give the required operate currents at the nominal P.D. of the battery (2 volts per cell). They are inserted on the adjustment chart solely to give the maintenance man some guide as to the value of resistance that he will require for his tests, and prevent his burning out the coil or making unnecessary tests.

Operating Time.

The operating "lag" or time of a relay is that time which elapses between the application of the saturate current and the operation of all the contacts, unless some particular contact, for example the *x* contact, is specified. The "max." and "min." times specified on the adjustment chart are "test values" and on readjustment the time lag to be aimed at is the mean.

There are so many complicated factors affecting the time lags of relays that the mathematical calculation of timing from first principles is outside the scope of this book. Some theoretical treatments have been worked out,* but fortunately the standardization of relay types into a few main categories enables the relay designer to use either empirical formulae or experimental curves for the determination of time lags with sufficient accuracy for ordinary needs. If these results do not meet what is required, then trial and error is at present the only safe way of obtaining

* See "The Principles of Relay Timing" (T. H. Turney, Ph.D., A.M.I.E.E.), *I.E.E. Jnl.*, Vol. 66, No. 376 (April, 1928).

a relay with given time lags. For purposes of routine calculation it is usually assumed that the greater portion of this time interval is absorbed in the building up of the flux to the operate value, after which the armature travels quickly and closes all the contacts practically simultaneously. This is not always true, however, but the determination of such armature movements is at present a matter of experiment in each individual case.

For a given type of relay with standard components, the operating lag is dependent upon a few variable characteristics of the relay and its circuit, the chief of which are as follows—

- (a) The magnetic circuit, i.e. the dimensions of slugs, etc
- (b) The operating ampere-turn adjustment
- (c) The excess, or "margin," of working ampere-turns over the above ampere-turn adjustment.
- (d) The air gap between armature and core (taken as stroke + residual)
- (e) The electrical inductance of the winding, measured

in terms of $\frac{T^2}{R}$ (T = turns, R = resistance)

The above scheme of variables is that used by Messrs Standard Telephones & Cables, Ltd., for their A.T.M. type relays, and for the purpose of rapid determination a series of experimental curves has been produced (Fig. 46), showing the relationship between operating time and the excess of working A.T. over the operating A.T. adjustment. Each graph has a number of curves for different armature air gaps, and one of these graphs is produced for each type of armature end slug or sleeve, and with various operating A.T. adjustments. For adjustments other than those for which graphs are drawn, the correct operating time is obtained by interpolation from adjacent graphs. A further correction is made for variations of the impedance from an assumed average, but since operating lag is directly proportional to $\frac{T^2}{R}$, a simple calculation can be made, or a

straight line graph can be prepared in order to save time.

The operating lag obtained in this way refers to that measured at the last contact to operate, but in cases where

frequently 70 per cent of the normal. This is of great importance in connection with unguarded intervals in automatic telephone circuits.

Consider the case of a uniselector* (rotary line switch) circuit having access to common equipment in which the "engaged" condition is indicated by the presence of earth on the "private" or guarding wire, *P*, and the disengaged condition by the absence of that earth. A skeleton circuit of such an arrangement is shown in the upper portion of Fig. 47, the guarding earth being applied by some relay contact. Normally, the uniselector magnet causes the switch to hunt rapidly from contact to contact, receiving current from earth on the engaged outlets, via the wiper, contact *K1* (break), and its own "interrupter" contacts; the same earth short circuits the *K* relay. When a disengaged outlet is reached, the earth potential is absent, the uniselector magnet cannot operate, and the *K* relay, being free from its short circuiting earth, now operates in series with the uniselector magnet (The current received by the magnet under this condition is insufficient to operate it)

If there were a momentary disconnection or "open period" in the guarding circuit of one of the outlets when the uniselector was searching, there would be a possibility of a double connection, i.e. a wrong connection of two circuits to the same outlet, provided that the open period was greater than the pulse-operating time of the *K* relay. This is made more clear with the aid of a time graph shown below the circuit in Fig. 47. The passage of time is represented by a scale in a vertical direction, and the events in each part of the circuit are indicated separately alongside the scale. In the example taken, at a time marked "20 mS." the guarding earth is disconnected: at 40 mS. the *K* relay is connected by the arrival of the uniselector wiper at an apparently disengaged outlet; at 70 mS. the guarding earth is replaced and short circuits the *K* relay although it has not operated; and yet at 80 mS. the *K* relay completes its operation, disconnects the short circuit at *K1* (break), and locks the *K* relay to the guarding earth at *K1* (make). This subsequent operation of *K* is made possible by the fact that the pulse-operating time of *K* is reached before it

* B.E.S.A. term, see Appendix II.

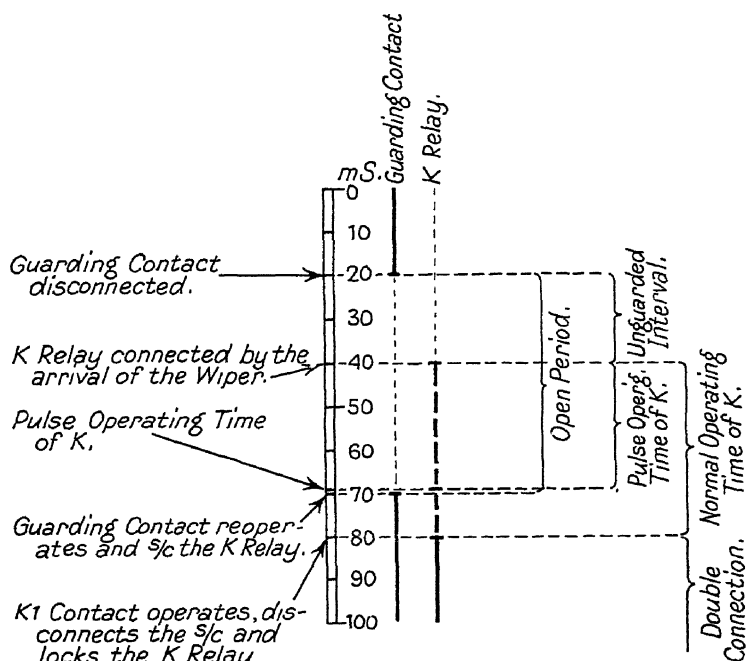
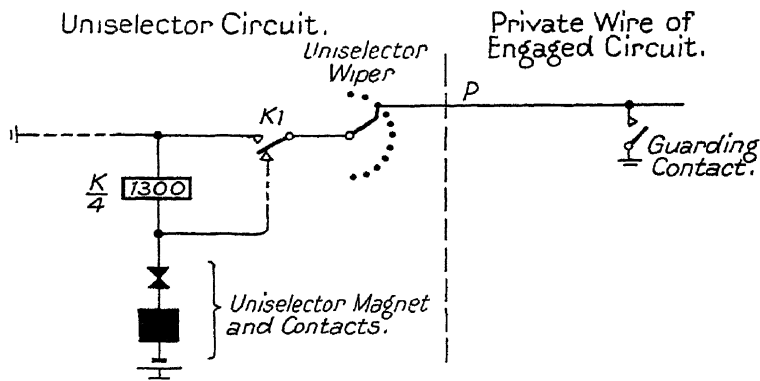


FIG 47 TIME GRAPH OF DOUBLE CONNECTION

is short circuited by the guarding contact. In the time graph the pulse-operating time is shown almost coinciding with the end of the open period, and this is a limiting condition, i.e. a condition in which the *K* relay is connected at the latest possible moment for a double connection to occur. The other limiting condition is that in which the *K* relay is connected at the earliest possible moment, i.e. by the removal of the guarding earth, so that the difference in time between these two conditions is the true "unguarded interval" of the system; it is the interval of time during which one circuit may be connected falsely to another as a result of an "open period" in the guarding condition.

Care should be taken to avoid confusion between the "open period," which refers to the condition of a circuit, and the "unguarded interval," which refers to a complete circuit operation.

Releasing Time.

The releasing "lag" or time of a relay is normally that time which elapses between the disconnection of the coil circuit and the opening or closing of the last contact to restore to normal, usually the contact nearest to the armature lever. According to this general definition, if an *x* contact were fitted, the releasing lag should include the release of this contact also. In many cases, however, the most important releasing lag is that of the main spring assembly, and if that value is quoted a note concerning the method of test should be added.

Although a large number of spring assemblies on a relay tends to produce a longer armature "travel time" on operation, it produces a shorter travel time on release. Therefore although the gauging of the various contacts may be different, there is considerable justification for assuming that the greatest part of the releasing time is taken up in the reduction of the flux to a value at which the armature can no longer remain attracted to the core, after which the armature restores to normal immediately.

As with operating times, the calculation of the releasing time is best made from experimental curves. Assuming that a relay is of a standard type of construction and that

the electrical and magnetic characteristics of the materials are also standardized, the releasing lag of a relay is dependent on the following variables—

- (a) The magnetic circuit, i.e. the dimensions of slugs, etc.
- (b) The normal working ampere-turns
- (c) The release ampere-turn adjustment.

The third variable, "the release ampere-turns," covers

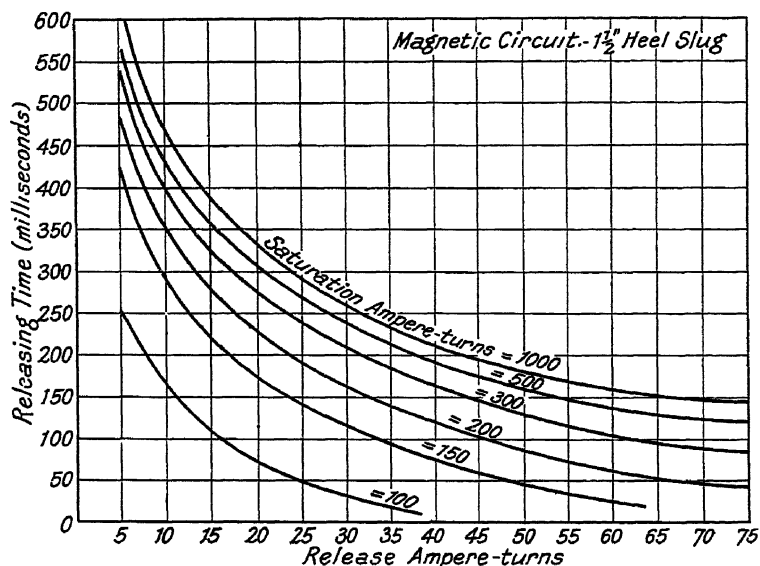


FIG 48 CURVES OF RELEASING TIME

all variations in spring assembly, load, gauging, residual gap, etc., because each of these is reflected in the value of the release current. Hence the determination of releasing lag is simpler than that of operating. Messrs. Standard Telephones & Cables, Ltd., have a short series of graphs applicable to their relays, one being produced for each type of magnetic circuit. Each graph contains separate curves for various values of working or "saturation" ampere-turns, and the curves themselves show the relationship between release ampere-turns and releasing time (Fig. 48). Increase of the normal working ampere-turns beyond the saturation

value for the iron has little effect on the releasing lag, and since the majority of slow releasing relays are working above this limit, this variable may be neglected for approximate calculations.

The effect of short-circuited windings on releasing lag may be calculated as for operating lag, the increase in time being proportional to $\frac{T^2}{R}$, where T is the number of

turns in the short-circuited winding and R is the internal resistance of that winding, together with any resistance in the "short circuit." The same applies to single coil relays releasing on short-circuit. Relays releasing in parallel or shunted by a resistance may also be dealt with in a similar manner.

After considering the normal tolerances on the variables affecting releasing lag, the calculated maximum and minimum values of time are closer together than was the case with operating lags, a ratio of 1.5:1 being typical. With slow releasing relays, however, it is very difficult to keep the time lag constant during the life of the relay, owing to the flattening of the residual screw and also to the penetration of the screw through the protective plating on the pole face. Thus, when a relay is in use, there is a distinct tendency for the releasing lag to be increased beyond the calculated maximum, especially if the armature is so pivoted that it strikes the core at an angle.

Special Conditions Affecting Relay Functions.

Apart from the variables considered in the previous paragraphs, there are certain other local conditions which affect time lags, and also current adjustments.

Vibration of the mounting rack on which the relays are fitted will reduce the release current, and, therefore the releasing lag, by making the armature fall away at a higher value of flux than usual. This vibration may either be regular, such as would be produced by adjacent rotating machinery, or may be intermittent, as in the case of the operation of adjacent magnets. In any case, the effect cannot be determined except by experiment under working conditions.

Heating of a relay by the current passing through it has a complex effect, owing to the alterations in the characteristics of each of the materials used in the relay. The greatest effect is the increase in resistance both of the coil winding and of the slugs, if fitted. The operating lag is lengthened by the increase in coil resistance, but reduced by the increased slug resistance, because of the reduced eddy currents: the releasing lag, however, is shortened by both effects and is, therefore, affected considerably. Another change caused by heating is a reduction in the spring tension causing reduced operate current, reduced operating lag, and increased releasing lag. Permeability of the iron is also affected slightly, but the change is dependent on the particular material used. It is difficult to give exact figures for heating effects owing to variable conditions of atmosphere, mounting, duration of heating test, etc., but, as an example, an 800 ohm slow-releasing relay (a selector B relay), when subjected to a prolonged heating by the application of 50 volts, has a temperature rise of 15° C. measured at the outside of the coil, and a resistance increase of 10 per cent; there is also an operate current decrease of 7 per cent, an operating lag unchanged, and a releasing lag decrease of 10 per cent. In this typical case, the energy dissipated was 3 watts, but with most relays 6 watts can be dissipated without damage to the insulation. If a relay has such a resistance that it is not damaged by being connected directly across the main 50 volt battery, it is said to be "self-protecting."

Metal relay covers have some effect on time lags, since eddy currents can be induced in them just as if they were slugs or sleeves. The effect is of importance in the case of slow releasing relays, the lag being increased in some cases by about 10 per cent by the fitting of an ordinary selector cover.

Magnetic interference between relays on the same mounting plate is unavoidable, owing to the air gaps in the normal magnetic circuit of each relay. This interference may assist or oppose the normal flux, according to the relative polarities of the adjacent relays, and is of the order of 10 per cent with some types of relay.

CHAPTER VII

IMPULSING

Loop Impulsing Circuit.

THE word "impulsing" refers to the regular making and breaking of the current in a circuit for the purpose of transmitting a number, in the form of a train of impulses, from one end of a line to the other. The elementary case is that of the dial, which is operated by a subscriber or operator, and which interrupts the current in the line to operate a selector magnet. It is not convenient, however, to connect the magnet direct to the line, especially as the magnet must be energized at each *break* impulse; the impulses are repeated from the line circuit to the magnet circuit by means of a specially designed "impulsing relay." (Relay *A* in Fig 49.)

The illustration shows how a single break-make contact of *A* is used to operate either the vertical magnet, the rotary magnet, or the release magnet in a selector, merely by control of the impulses from the dial. The method of operation is, briefly, as follows*—

Normally, when a call is being made, the dial contacts are closed, the *A* relay is operated, and the "guard relay" *B* is operated by *A1*. During the first train of impulses at normal impulse frequency and ratio, the *B* relay remains operated owing to its slow releasing properties, and therefore, at each break of the dial springs the vertical magnet *V* is stepped via *B1*, *N2*, and the low resistance "impulse control relay" *C*. This relay is also slow releasing and, once operated at the first impulse, it remains operated for the rest of the train of impulses. At the first operation of *V*, the shaft is lifted and the off-normal contacts *N* operate, contact *N2* provides an alternative path for the vertical magnet current via *C1* (now operated). At the end of this first train of impulses, known as the "vertical train," the

* For a description of the full circuit operation, see *Automatic Telephony Simplified* (C. W. Brown).

dial contacts remain closed until the dial is re-operated for the next train and, during this pause, contact *A1* remains operated and *C* and *V* receive no current; consequently, *C* releases after the lapse of its slow release period, and the *C1* contact prepares a path for the next train of impulses (the rotary train) to operate the rotary magnet *R* instead

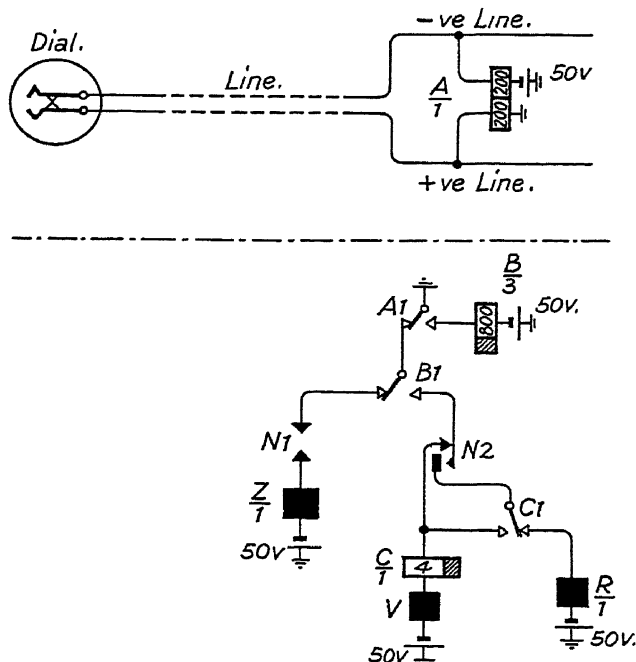
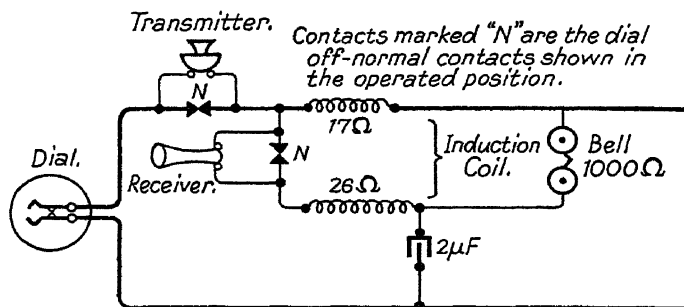


FIG 49. SIMPLE LOOP IMPULSING CIRCUIT

of *V*. This magnet steps the shaft in a rotary direction to a position in accordance with the impulses repeated at *A1*, and the shaft remains in this position so long as *A* and *B* are operated. A selector mechanism is shown in Fig. 32.

To release the selector it is necessary to disconnect the *A* relay either permanently or at least for an impulse of greater duration than the releasing lag of the *B* relay.

Thus, when *A* releases, *B* also releases, and the release magnet *Z* will be energized until the off-normal contacts *N*1 are opened, thus ensuring that the *Z* magnet is operated only for so long a time as is necessary for the complete release of the shaft to the normal position.



G.P.O. Standard Auto-Telephone Circuit
showing Loop Impulsing Condition.

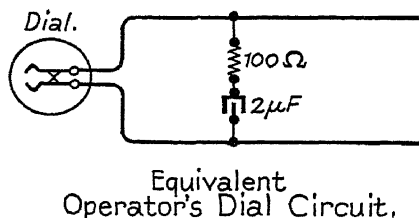


FIG. 50. THE DIAL CONDENSER

Dial Condenser.

In Fig. 49 the dial is shown connected direct to the line, an arrangement which at first sight appears to be the most satisfactory and which was adopted in earlier subscribers' telephone instruments.*

The latest instruments have circuits as shown in Fig 50, and it is deliberately arranged that as soon as the dial is "off-normal," the condenser, together with the low

* For further information, see "Subscribers' Apparatus in Automatic Areas" (H. G. S. Peck) *P.O.E.E. Jnl.*, Vol. 20; October, 1927.

resistance induction coil, is shunted across the line. The reasons for this arrangement are as follows—

(a) A condenser normally bridging the two wires reduces the inductive voltage on the line during impulsing. This P.D. may be of the order of 700 volts when a simple impulsing circuit is used, but it is reduced to 150–200 volts by the use of the dial condenser. Thus the condenser has a beneficial effect on the possibility of breakdown of the insulation of the line, and it also acts as a spark quench for the dial contact when it breaks the current.

(b) The condenser assists in stabilizing the lags of the impulsing relay under varying line conditions, particularly with leaky lines. The particular capacity used, 2 μ F., gives the best all-round performance in this respect.

(c) The retention of a condenser during impulsing permits the use of a subscriber's telephone circuit which is free from bell tinkling during dialling. Not only is the inductive voltage of the line reduced, but the bell is shunted by a comparatively low resistance, as can be seen from Fig 50.

As with all spark quenches, a resistance in series with the condenser (not necessarily inductive) is required to prevent welding of the dial contacts when they short circuit the dial condenser, the potential of which may be about 200 volts, as has been pointed out. In the subscriber's telephone circuit the series resistance is conveniently provided by the bell and induction coil, but in other cases, e.g. operator's dialling circuits, impulse machines, etc., a separate non-inductive resistance of 40 or 100 ohms is used. The actual value of series resistance is not critical.

Impulsing Requirements.

From the previous description of the impulsing circuit it will be apparent that the normal break period of each impulse must be sufficiently long to operate the *V* or *R* magnet together with the *C* relay, but must not be so long that the *B* relay will release; conversely, the make period must be long enough to rebuild the flux lost by the *B* relay during the preceding break, and to allow the magnet armature to release between steps, but it must not be so long that the *C* relay will release prematurely. (See p. 127.)

There is a certain range of impulse times which will fulfil these requirements, and if the line conditions were constant there would be little difficulty in obtaining correct repetition by the impulsing relay *A*, merely by arranging equal releasing and operating lags. A summary of the variations which must be catered for, however, is given below. All affect the releasing and operating lags of the *A* relay to some extent, but some have a direct effect on the operation of the selector magnets and other relays. The precise effect of each will be considered later.

FREQUENCY LIMITS. The normal frequency of impulsing is 10 impulses per second, but selectors must operate on 7 to 14 i.p.s. from dials, although the frequency of a correctly adjusted dial should be 9–11 i.p.s.

RATIO LIMITS. The ratio of the break period to the total impulse (make plus break) is expressed as a "percentage break" or "break ratio," and is nominally 66·6 per cent. A range of 63 per cent to 70 per cent is permitted. An alternative expression is that the "break-to-make ratio" is 2 : 1.

VOLTAGE LIMITS. The range of voltage catered for in a telephone exchange is on the basis of 1·85 to 2·1 volts per cell of the exchange battery. Thus, in a 50 volt exchange (25 cells), the voltage range is 46 to 52. This is on the assumption that the cells are never "floated," i.e. charged whilst delivering current to the exchange.

LOOP LIMITS. The maximum loop resistance (i.e. the total resistance of the two wires in series) of subscribers' telephone lines in Great Britain has been fixed at 750 ohms for the impulsing condition. This figure includes any resistance in the subscriber's equipment, but excludes the impulsing relay and the exchange apparatus. Junction lines between exchanges may have a loop resistance up to 1,200 ohms, excluding the resistance of apparatus at both terminal points.

LEAK LIMITS. The greatest leak resistance permissible is 50,000 ohms for subscribers' lines or 100,000 ohms for junctions, irrespective of the length of the line, but usually tests are conducted with leaks of 20,000 ohms, since the effects of leak are so small as compared with those of loop resistance. Leaks may be of three types, either line to line, negative line to earth, or positive line to earth. A leak

from line to line has the greatest effect, and is assumed unless otherwise specified. It is the most likely to occur in the case of towns where underground cable is largely used.

ADJUSTMENT LIMITS. The range of adjustments of the apparatus (relays, magnets, etc.) cannot be specified in any simple form, since the number of possible variations is so great. Impulse distortion due to adjustments is usually catered for by providing a good margin of safety after studying the other working limits. The general effects of some of the simpler adjustment variations are given in the next chapter.

Impulsing Relays.

It is important that the impulsing relay shall have short releasing and operating lags in order that the variations of time which are bound to occur under the wide range of circuit conditions shall not have too great an effect on the impulses. Unfortunately for many of the more complicated impulsing circuits, particularly in connection with impulse repetition, the reduction of time lags must not be carried too far, as, otherwise, the relay will respond too easily to momentary condenser surges which occur at times when operation is not intended. The ordinary fast relay is taken as the basis of design, and the normal time lags are of the order of 8 to 12 mS., the adjustment varies with different manufacturers. These time lags, as also the operate currents, etc., are measured with the two windings in series.

The coil is designed to give balanced impedances in the two windings, and to this end the windings are either sandwiched (Siemens, Fig. 4) or else two separate coils are used with a centre check between them (A.T.M., Fig. 7). Another alternative, rarely used for impulsing, however, is the winding of the two circuits simultaneously, so that each turn of one corresponds to an exactly similar turn of the other. It should be noted that, although the two coils may have equal impedances, they are not necessarily of equal efficiency from an electro-magnetic point of view, and, therefore, they may have different operate currents when energized separately. On a typical A.T.M. relay with

an operate current of 14.5 mA. for the two coils in series, the operate current figures, separately, are 26.5 mA. for the heel end coil and 30.5 mA. for the armature end coil. The difference is somewhat less in the case of sandwiched windings. Impedance characteristics are considered in greater detail on page 60.

The contact springs of normal selector impulsing relays are three in number and form either a break-make or a make-before-break assembly. The time interval between make and break, i.e. the "change-over time" or a "transit time" on operation or release, is wasted in a break-make combination, but is added to both break and make periods in the case of MbB contacts. Thus, if the change-over time on operation were 4 mS. and the total impulse took 100 mS, a 67 per cent break impulse repeated without distortion would appear as 65 per cent break and 31 per cent make in the one case, and 69 per cent break and 35 per cent make in the other.

A short travel of armature is necessary for fast operation, and for this reason the gauging adjustment of the A.T.M. standard impulsing relay with break-make contacts is "break at 6 mils, make at 4 mils," with an armature travel of 10 mils. With MbB contacts, however, as used on Siemens relays, the travel must be greater than this, a figure of 22 mils being typical.

The subject of contact bounce has been considered in Chapter II, but it may be stated as a general rule for impulsing relays, that the A.T.M. type is more liable to give bounce on the break contact, and the Siemens type on the make contact. Contact bounce is rare, however, under long line conditions. (Compare the oscillograms in Fig. 55, *a*, *b*, and *d*.)

Residual magnetism is of great importance in a relay which has to impulse accurately at high speed, and its effects are therefore minimized by the introduction of air gaps. On some relays a brass washer is inserted between the core and the heel end of the yoke for this purpose. On the G.E.C. impulsing relay (Siemens type) a special pin type armature is used in place of the knife-edge type, merely to introduce the hinge air gap. On all types of impulsing relay a large residual screw adjustment is

specified, e g 9 mils, in order to retain a considerable gap between armature and core when the relay is operated.

On Siemens type relays an isthmus or perforated armature is frequently used: common types are shown in Fig. 51. They are ordinary armatures which have been cut or drilled so that the flux must pass through a narrow neck or "isthmus". The effect is to produce magnetic saturation at this point at a low value of current, so that the flux is approximately the same whether the relay is operated at high or low voltage, long or short lines, and, consequently, the releasing lag is to some extent shortened and also stabilized. This effect is more noticeable at normal impulse frequencies than on simple operating and releasing lag tests, there being a reduction of about 4 per cent in the amount of distortion produced when the loop resistance is increased from zero to 1,200 ohms. The improvement is less when a dial condenser is used, because the releasing lag is fixed to some extent by the condenser surge.

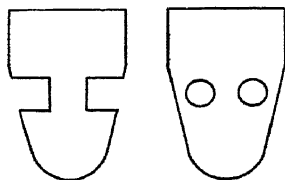


FIG. 51 ISTHMUS AND PERFORATED ARMATURES

Loop Variation.

The effect of adding resistance in series with the impulsing relay is the reduction of the current and flux, and this affects both releasing and operating lags.

RELEASING LAG. The reduction of the ultimate flux allows the relay to release more quickly when the break impulse commences, thus lengthening the break period. Fig. 53 shows the variations in the normal releasing time of a relay which has equal operating and releasing lags at 0.1 p.s., i.e. when tested for normal time lags. It will be seen that the reduction of releasing time is not uniform, being small until the flux falls below the saturation value at about 400 ohms loop resistance, after which the effect is greater.

OPERATING LAG. The reduction of the flux also involves a reduced speed of growth, and this causes an increase in the operating time which lengthens the break period still

further. Fig. 53 shows this also, and since saturation does not affect speed of growth, the increase in operating lag is uniform

Leak Variation.

The general effects of leaks from one wire to the other are opposite to those of loop resistance. For this reason,

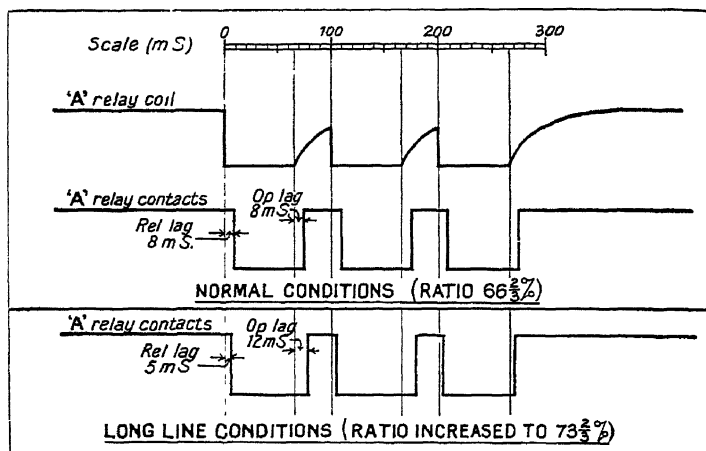


FIG. 52 EFFECT OF TIME LAGS ON RATIO

when making leak impulsing tests, the loop resistance is reduced to zero.

RELEASING LAG. The leak tends to keep the impulsing relay operated and therefore delays the release of the impulsing relay, as can be seen from Fig. 53. A reciprocal scale of leak resistance is used on this graph in order to show leakance instead of resistance. The real resistance figures are inserted, however, for convenience in reference.

OPERATING LAG. The permanent current produced by the leak also assists the impulsing relay in its operation, but the effect on operating lag is much less than on releasing lag.

Effect of Frequency on Line Variations.

The theoretical break ratio variations at 10 i.p.s. may be calculated from the normal operating and releasing lags

in the manner shown in Fig. 52. A useful rule to remember in this connection is as follows—

Increase in operating lag gives increase in break ratio.

Increase in releasing lag gives decrease in break ratio.

Calculations on these lines give the curve of ratio shown by the broken line in Fig. 54, but when the makes and

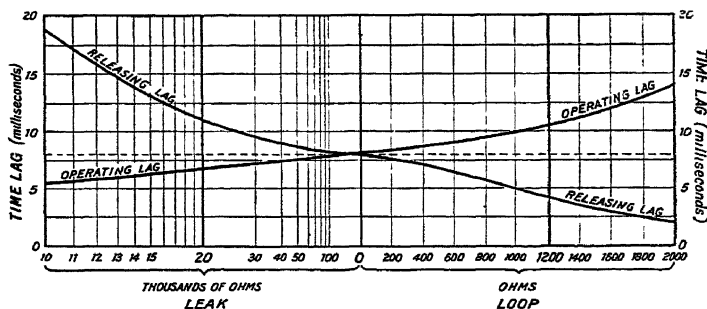


FIG. 53. EFFECT OF LINE RESISTANCE ON TIME LAGS

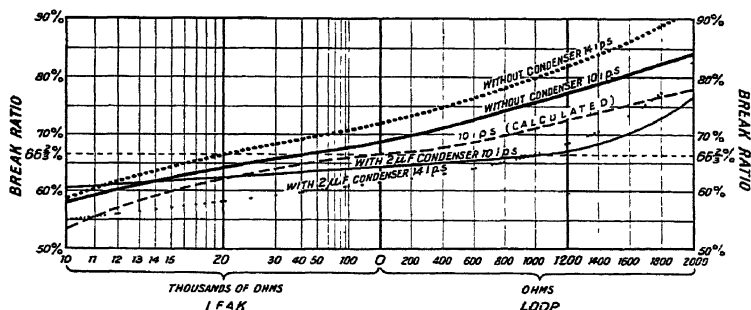


FIG. 54. EFFECT OF LINE RESISTANCE ON RATIO

breaks follow each other in rapid succession there is less chance for the relay to reach the saturation flux during the short period of make, this causes a further decrease in the releasing lag, and, therefore, a further increase in the break ratio. The increase is about 3 per cent at zero loop resistance and is greater with long lines.

The first impulse of a train is not affected by frequency in the same way, because the saturation of the relay before

impulsing commences is independent of the frequency. This difference between the first impulse and the remainder is not of very great importance, except in the case of complicated impulse repeating circuits, where condenser surges play an important part.

If the frequency is increased from 10 to 14 i p s, the ratio distortion should be amplified because the normal distortion by the relay, as measured in milliseconds, is now expressed as a proportion of a total impulse of 70 mS instead of 100 mS. The fact that the 10 and 14 i.p.s. curves do not cross at the point of zero distortion, however, confirms that the ratio is being modified independently by the saturation effect at higher frequencies.

Effect of Dial Condenser on Line Variations.

These effects are best studied with the aid of oscillograms,* some examples being shown in Fig 55. Oscillograms (A) and (B), taken with a simple impulsing circuit (without condenser), show how the rising current in the coil of the impulsing relay is cut off sharply at the end of each make period, the current remaining steadily at zero until the next make period commences. Oscillogram (C), however, was taken under exactly the same conditions, except that a 2 μ F. condenser and 40 ohm resistance was shunted across the dial, the result is that there is an oscillation of current during the whole of the break period.

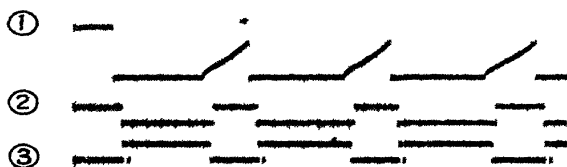
During the make period of the dial the condenser is short circuited, but when the impulsing contacts break the condenser commences to charge up, and, in doing so, draws current from the impulsing relay in the operating direction. This current cannot persist indefinitely, however, but falls gradually as the potential of the condenser increases. Moreover, an oscillatory circuit is involved, consisting of the inductance of the impulsing relay together with the capacity of the condenser, so the curve of current takes up a definite wave form, as shown in oscillogram (C). These waves are damped out rather rapidly, and only one negative wave is noticeable, yet it is this negative wave (occurring about 15 mS. after the break) which exercises control over the

* For a description of the preparation of oscillograms, see p. 144.

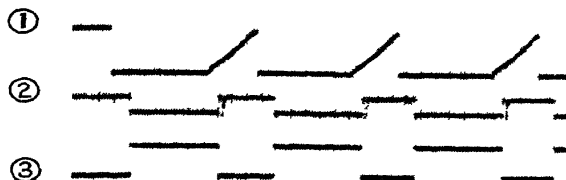
① *Current in A relay coil*

② *A1 make contact*

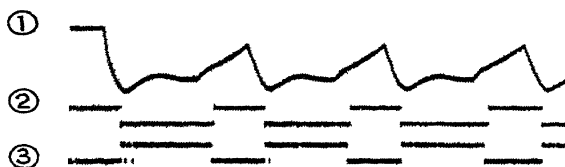
③ *A1 break contact*



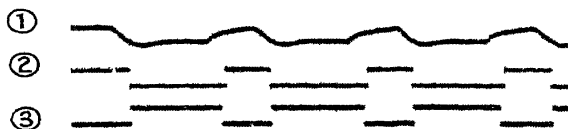
Ⓐ Zero line, without condenser (A.T.M)



Ⓑ Zero line, without condenser (Siemens)



Ⓒ Zero line, with $2\mu f$ condenser



Ⓓ 1200 ohm line, with Sub's. Tele.

FIG 55. IMPULSING WAVE FORMS

timing of the impulsing relay. It causes the releasing lag to be fixed at about 11 mS., representing, in the relay under consideration, an increase of 3 mS. at zero line. The dial condenser has no appreciable effect on operating lag.

The effect of leak resistance on releasing lag is considerably reduced by the condenser because the addition of leak resistance cannot alter the frequency of the condenser oscillation, and this oscillatory current, which stabilizes the lag, is much greater than the usual leak current. Under extreme loop resistance conditions, however, the condenser surge is damped out and there is no such stabilization. In short, the effect of the dial condenser is to reduce the ratio distortion under all leak conditions and all loop conditions not exceeding about 800 ohms, after which the rate of increase of ratio with loop resistance is very rapid. (Fig. 54.)

The fact that Fig. 54 shows some distortion at zero line is of little importance, because all of the graphs reproduced here are based on an impulsing relay which has been adjusted to have equal time lags under normal operating and releasing conditions. In practice, an adjustment would be chosen such that no distortion would occur under the most common working conditions. This might be with or without a dial condenser, and either at zero loop or at some other more common loop resistance according to local conditions. In other words, it is "variation of distortion" and not "actual distortion" which is of greater importance.

Effect of Dial Condenser on Frequency Variations.

With the simple impulsing circuit considered previously, the effect of high impulse frequency within practical limits of loop and leak resistance has been shown to be an increase in the break ratio, owing to the reduction of the maximum flux and consequent decrease in releasing lag. When a dial condenser is used, the releasing lag is kept constant by the condenser, irrespective of maximum flux, so that the effect of increase in frequency is confined to such variations in distortion as are to be expected from the reduction of the total impulse period. Thus, the 10 and 14 i.p.s. curves (Fig. 54) cross at the point of zero distortion. The crossing

of the frequency curves does not mean that the frequency is wholly unimportant under these conditions, as in a later paragraph dealing with the analysis of selector failures it will be seen that much less distortion can be tolerated at high frequencies, owing to the requirements of the vertical and rotary magnets.

Target Diagrams.

The use of target diagrams constitutes a convenient method of analysing the performance of impulsing apparatus, particularly in the case of a selector mechanism, because it shows at a glance the margins existing for the safe operation of each component. This scheme was devised by Messrs. Siemens Bros., and a typical target diagram of a group selector is shown in Fig. 56.

Consider, first, the lay-out of the special graph paper. Vertically the scale is marked in milliseconds of break period, whilst horizontally the scale is in milliseconds of make period, the first few milliseconds being omitted in each case, because they are so seldom used. The scales, however, are not linear but logarithmic, for reasons that will be explained later. Since the dimensions of the scales are the same, the ratio of break to make (or, alternatively, break percentage) will be expressed as a straight diagonal line, and a number of diagonals representing ratios from 10 per cent to 95 per cent are marked on the graph paper as a guide when preparing the records of a selector operation. Similarly, it is possible to construct curves of constant frequency by completing points at which the period of "make plus break" is a constant. A number of curves for frequencies from 2 i.p.s. to 70 i.p.s. are shown.

On the usual form of target diagrams the frequency and ratio limits of a subscriber's dial are picked out in bold lines, so that at the centre of the diagram there is a "dial target," which is approximately rectangular and is bounded by the 63 and 70 per cent diagonals, and by the 7 and 14 i.p.s. curves.

Performance of Selectors.

In order to represent on a target diagram the overall performance of a selector, tests are conducted by means

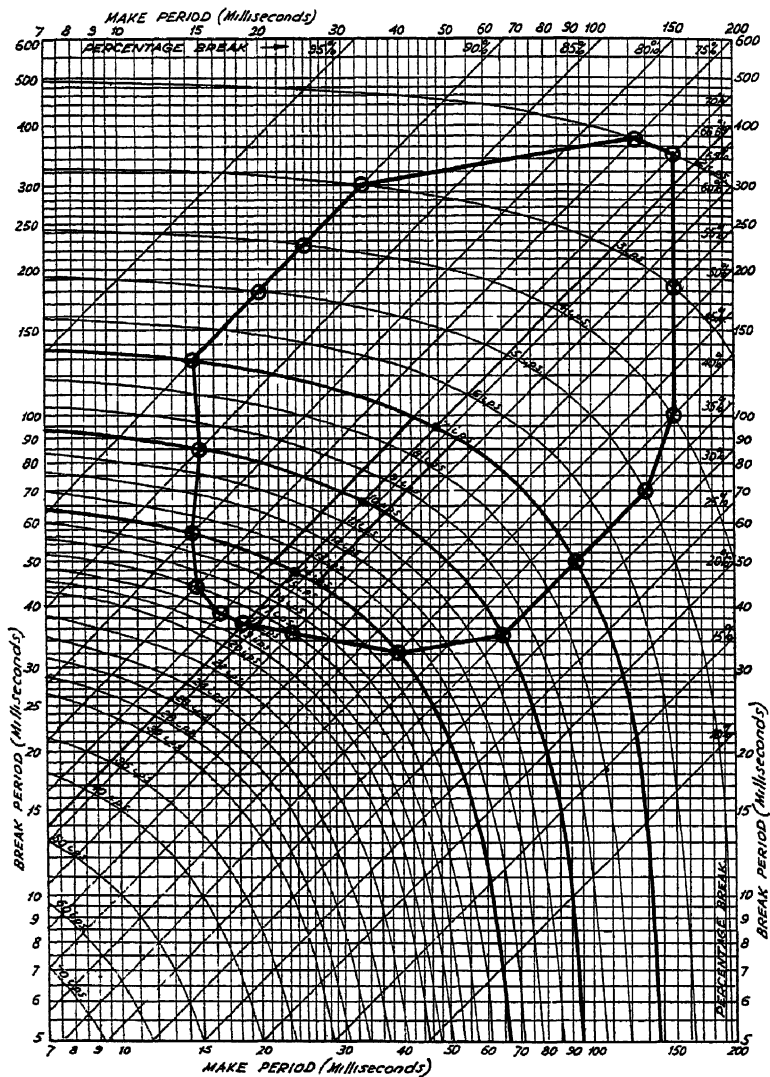


FIG. 56. TARGET DIAGRAM

of a variable impulsing machine, a machine in which the frequency and the ratio of impulses may be varied over a wide range. The machine is set at, say, 10 i.p.s., and these impulses are made to step the selector under test. This is repeated and the break ratio is increased until a point is reached, say at 85 per cent break, when the selector fails, due to the distorted ratio. The point of intersection of the 10 i.p.s. curve and the 85 per cent ratio line is marked on the diagram (Fig. 56). Similarly, at the same frequency there will be a certain minimum ratio at which the selector will function correctly, say at 35 per cent, and this point is also plotted on the 10 i.p.s. line. Further points can be obtained at other frequencies, and the limits are marked up on the diagram in the same way, until a maximum and a minimum frequency is reached at which the selector will not function at any ratio. If, then, all the points plotted are joined up, a closed figure results, and this is called the "target diagram" of the selector.

It follows that for correct operation this closed figure must always lie outside the dial target. For example, if it cuts the target at the 14 i.p.s. end, it means that the selector will not function with high frequency dials. This seldom occurs in the case of new switches, but the closeness of the target diagram of the selector to the dial target is some measure of the margin of safety which is available. Moreover, the use of a logarithmic scale for the make and break periods causes the linear dimensions in all directions to be of approximately equal value as regards impulsing efficiency.

Analysis of Selector Failures.

Having found which part of the closed figure is nearest to the target, it is possible to determine which part of the selector is at fault.

The impulsing relay controls three separate components: the *B* relay, the *C* relay, and the stepping magnet (vertical or rotary), and a theoretical target diagram for the selector can be constructed from a knowledge of the characteristics of each item.

The *B* relay, as explained in the sequence of operations on page 112, must remain operated although it is

disconnected during the break periods of the impulses and re-energized only during the short make periods (Fig. 57(b)). Therefore, at all normal frequencies, the ratio of break to make must not exceed a certain figure, according to the characteristics of the *B* relay. If this is 90 per cent break, then the 90 per cent break ratio diagonal represents the boundary of the target diagram at which *B* relay failure will occur. This is marked on Fig. 58. At low impulse frequencies there is a limit to the actual break period, measured in milliseconds, determined approximately by the normal releasing lag of the relay under saturation conditions. If this is 360 mS, then the horizontal line corresponding to this value forms a secondary boundary of the target diagram for the selector. This boundary, and also the preceding one, is marked "*B* releasing" in Fig. 58.

The *C* relay is energized by the break contacts of the impulsing relay, and therefore is energized during the break period and disconnected during the make (Fig. 57(c)). It must remain operated during impulsing, and is therefore subject to the same conditions as the *B* relay if for "make" were read "break" and vice versa. Typical limits are 35 per cent minimum break (which is the same as 65 per cent maximum make) and 150 mS. normal releasing lag, so that these two lines form further boundaries in the target diagram.

In addition, the *C* relay must make its initial operation during the first break impulse (Fig. 57(c)), and therefore a minimum break period is required. However, the value is usually much higher than the minimum break period required for the vertical or rotary magnet, and therefore it may be ignored.

The vertical magnet (or the rotary magnet), which is also energized by the break contacts of the impulsing relay, is different from the *C* relay in that it must release instead of hold during each disconnection period (the make period of the dial), and as it has a certain releasing lag, approximately 15 mS., the make period of the dial must not fall below this value. Again, since the magnet must operate during each break period of the dial, there is a pulse-operating lag of, say, 36 mS., below which the break period of the dial must not fall. This "pulse-operating lag" refers

not only to the movement of the shaft, but to the full operation of the magnet armature, in which position a pawl on the armature engages with a front stop and prevents the shaft from taking more than 1 step at a time. If there is

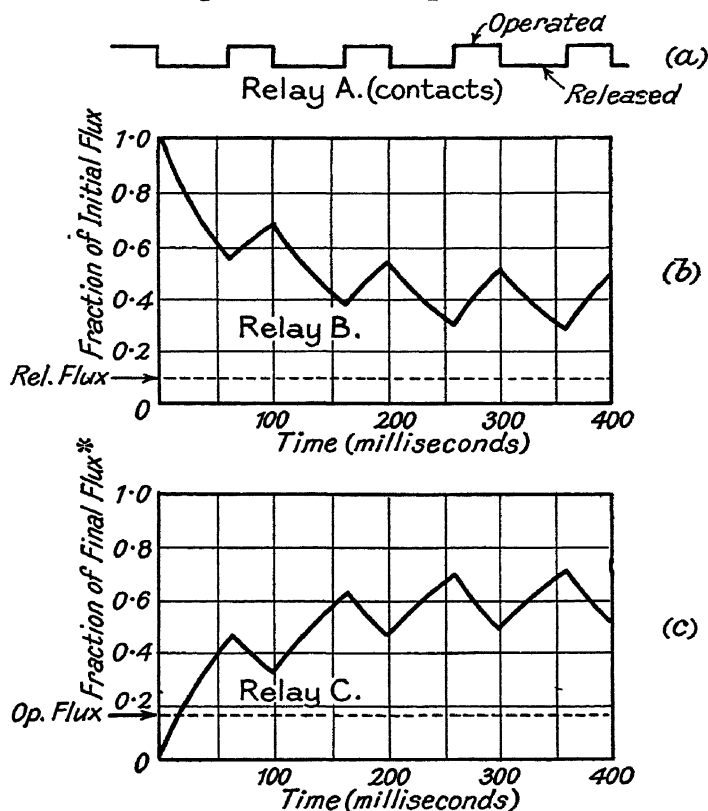


FIG. 57. FLUX TIME GRAPHS OF B AND C RELAYS
(* Saturation effects have been ignored)

insufficient break period for this "locking" to take place, the shaft may overstep, often reaching the tenth position with 3 or 4 impulses. These limits of operating and releasing time complete the boundaries of the diagram in Fig. 58, and, subject to slight variations resulting from changes in

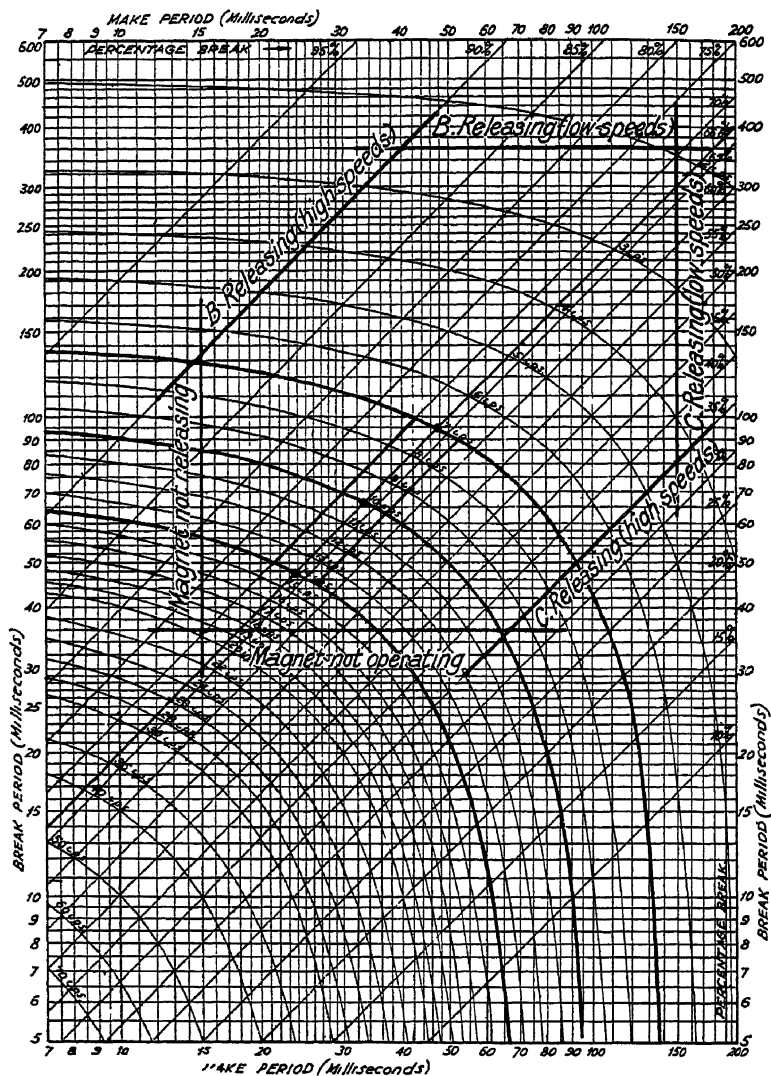


FIG. 58. TARGET DIAGRAM ANALYSIS

operating and releasing lags of the magnet at different ratios and a few other factors, the closed figure represents the target diagram of the selector.

From this analysis it is possible to determine which part of a selector circuit is liable to fail, when the margin of safety between the dial target and the target diagram of performance is small in some given direction.

CHAPTER VIII

FURTHER IMPULSING CONSIDERATIONS

Effect of Cable.

IN the previous chapter the line conditions for impulsing were measured in terms of non-inductive resistance, and this is reasonably accurate for overhead lines. When underground cables are used, however, the capacity between the wires is important, although it usually gives an improved performance on impulsing. The basis of comparison is the Standard Cable, which has the following characteristics—

Weight of conductor	.	.	.	20 lb. per mile
Resistance	.	.	.	88 ohms per mile
Distributed capacity	.	.	.	0.054 μ F. per mile
Distributed inductance	.	.	.	1 mH. per mile
Leakage	.	.	.	1 M Ω per mile
(A.C. tests at 800 cycles per second.)				
1 Standard Mile = 0.9221 Decibels.				

Lengths of artificial cable, with tappings at various points, are available in convenient form for testing purposes.

It has been shown in Chapter VII that, under ordinary non-inductive loop resistance conditions, the effect of the resistance is to increase the break ratio, owing to the lengthened operating lag and reduced releasing lag. Also, a capacity between lines increases the releasing lag and shortens the break ratio. Thus, it will be seen that, if the

Impulsing Circuit	Fro- quency	Voltage	Length of Cable
Simple impulsing {	7 i.p.s.	46	19½ miles (1700 ohms)
	10 ..	50	21½ .. (1900 ..)
	14 ..	52	23½ .. (2060 ..)
With dial condenser {	7 ..	46	17 .. (1500 ..)
	10 ..	50	18 .. (1850 ..)
	14 ..	52	22 .. (1940 ..)

capacity is increased in proportion to the loop resistance, the two effects will tend to cancel out, and this, in general, is the condition provided by underground cable. The table on page 132 shows the lengths of standard cable which give a distortion equal to 1,200 ohms non-inductive loop resistance

It is seen from this that, even under the worst conditions, a 1,200 ohms non-inductive line is equivalent to 1,500 ohms of standard cable. With very long lines, the beneficial effect of cable capacity is nullified somewhat by the excessive distortion of the wave form.

Effect of Extension Telephone.

In some circumstances a subscriber has an extension bell, together with its condenser, connected in parallel with the normal instrument. Thus, when the telephone is being used for dialling, the additional bell and condenser remain shunted across the line, giving the effect of an increase in the capacity of the dial condenser. There are various extension arrangements of this kind, but taking as a typical example an additional 1,000 ohm bell with a 2 μ F. condenser, the average increase in break ratio is 3 per cent. The effects of the dial condenser are amplified in other ways also

Effect of Transmission Bridge.

Impulsing into final selectors is different from the simple impulsing case, because the *A* relay is permanently connected to a "Stone" transmission bridge, consisting of a 2 μ F. condenser in each line and a double-wound relay *D* bridging the outgoing lines, as shown in Fig. 59 (a). The effect on the wave form is similar in principle to that of the dial condenser, but it is less in extent owing to the inductance of the *D* relay in the circuit; also, the effect is not reduced by resistance in the incoming line. The result of adding a Stone transmission bridge to an impulsing circuit is a decrease in ratio of the order of 3 per cent under most conditions.

A repeating coil bridge, as shown at (b) in Fig. 59, has an effect even greater than a Stone bridge since the condenser (either 2 μ F. or 4 μ F.) is shunted directly across the

A relay. In addition, the inductance of the repeating coil impedes the operation of the relay. This circuit is rarely used for impulsing.

Effect of Voltage.

The distortion considered in the previous chapter refers to that at the normal exchange voltage of 50, but a range

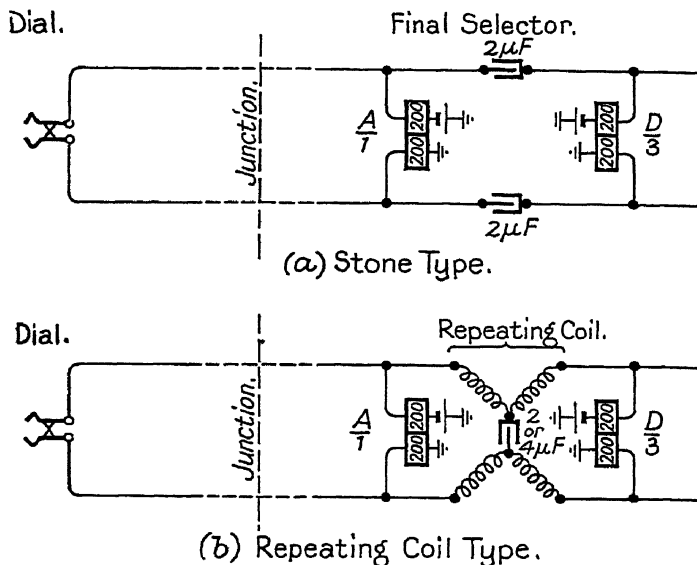


FIG. 59. TRANSMISSION BRIDGES

of 46–52 volts must be considered. Voltage has a greater effect on operating time than on releasing time, even under long line conditions where saturation effects are eliminated, and, therefore, the additional distortion is approximately the same either with or without a dial condenser. It follows, however, that, since voltage variation adds to, or subtracts from, the time lags a fixed number of milliseconds, the effects will be greater at high impulse frequencies. This is shown in the following set of results taken from the performance of the same relay that was considered previously, i.e. having equal operating and releasing times of 8 mS.

DECREASE IN VOLTAGE CAUSES—

Increase in operating time.

Decrease in releasing time.

At 10 i.p.s.: $\frac{1}{4}$ – $\frac{1}{2}$ per cent increase in ratio per volt drop.

At 14 i.p.s.: $\frac{1}{2}$ – $\frac{3}{4}$ per cent increase in ratio per volt drop.

The figures refer to the additional distortion between the line limits of 1,200 ohms loop and 20,000 ohms leak within which the effects of voltage are approximately uniform. With line conditions outside this range the effect of voltage is greater.

Effect of Operate Current Adjustment.

In order to reduce variation of performance due to change in adjustment, the operate and non-operate currents for the impulsing relay are specified as near to each other as practicable. A common figure for re-adjustment is: "operate at 14.5 mA., non-operate at 12.0 mA." An increased operate current adjustment (heavy spring pressure) has effects similar to those of reduced voltage, i.e. increased operating lag, and, to a lesser extent, decreased releasing lag and, on an average relay, variation of adjustment within the range of a few milliamperes causes approximately 1 per cent increase in operate current per milliampere.* This figure is increased to 1½ per cent at 14 i.p.s., but is practically unaffected by the use of a dial condenser.

Effect of Residual Adjustment.

The residual gap normally specified on the A.T.M. type impulsing relay is 9 mils, but a tolerance of ± 2 mils is usually allowed. In practice, there is a tendency for the residual screw to hammer a depression in the pole face of the core, thus reducing the effective residual gap. In this case, the releasing lag is lengthened, but the operating function is not interfered with. This causes a decrease in the break ratio, and, for an ordinary relay, the decrease is of the order of $\frac{3}{4}$ per cent at 10 i.p.s., or 1½ per cent at 14 i.p.s. for each mil reduction in residual gap. When a dial condenser is used, the effect on the releasing lag is minimized,

* See also "The Distortion of Dialling Impulses" (L. H. Harris); *P.O.E.E. Jnl.*, Vol. XVII; Jan., 1925.

and then the decrease in ratio is only $\frac{1}{2}$ per cent at 10 i.p.s. or $\frac{3}{4}$ per cent at 14 i.p.s. for each mil reduction.

Impulse Repetition.

The fundamental object of impulsing repeaters is the regeneration of the impulses at intermediate points on routes with a total loop resistance greater than 1,200 ohms. In practice, however, repeaters have to be employed at any intermediate point at which a signalling facility is required, e.g. where a route passes from an exchange three-wire system to a two-wire junction, and vice versa. Thus the loop resistance on either incoming or outgoing sides of the repeater may be quite small, and, therefore, the full range of loop and leak resistances must be catered for.

A skeleton circuit of a typical auto-auto repeater (loop impulsing) is given in Fig. 60. The incoming circuit which contains the dial, junction, and impulsing relay *A*, is the same as has been considered previously, but on the other side of the $2\ \mu\text{F}$. transmission condensers the lines are bridged by a shunt field relay *D* (for the reception of the metering signal) and a high impedance relay *I* (to prevent the leakage of speech currents). The guard relay *B* and the impulse control relay *C* are operated by the *A1* contacts in the same manner as in a selector (*cf.* Fig. 49), but the magnets *V*, *R*, and *Z* are not provided. In certain cases a repeater is combined with a selector, e.g. in a "Discriminating Selector Repeater," but the repeating function is always separated by various relay controls from the magnet stepping function. The *C* relay contact, *C2*, short circuits the *I* and *D* relays in order to cut out the high impedance during impulsing, a second contact of *A* being inserted in one of the outgoing lines for repeating the impulses. At the distant end of the second junction there is shown in Fig. 60 the skeleton circuit of a final selector.

If it were not for the electrical connections between the incoming and outgoing sides of the repeater, via the transmission condensers, the problems of impulse repetition would not be different from those of simple impulsing, but unfortunately the condensers provide paths for innumerable surges of current, which alter the characteristics of the impulsing relays considerably.

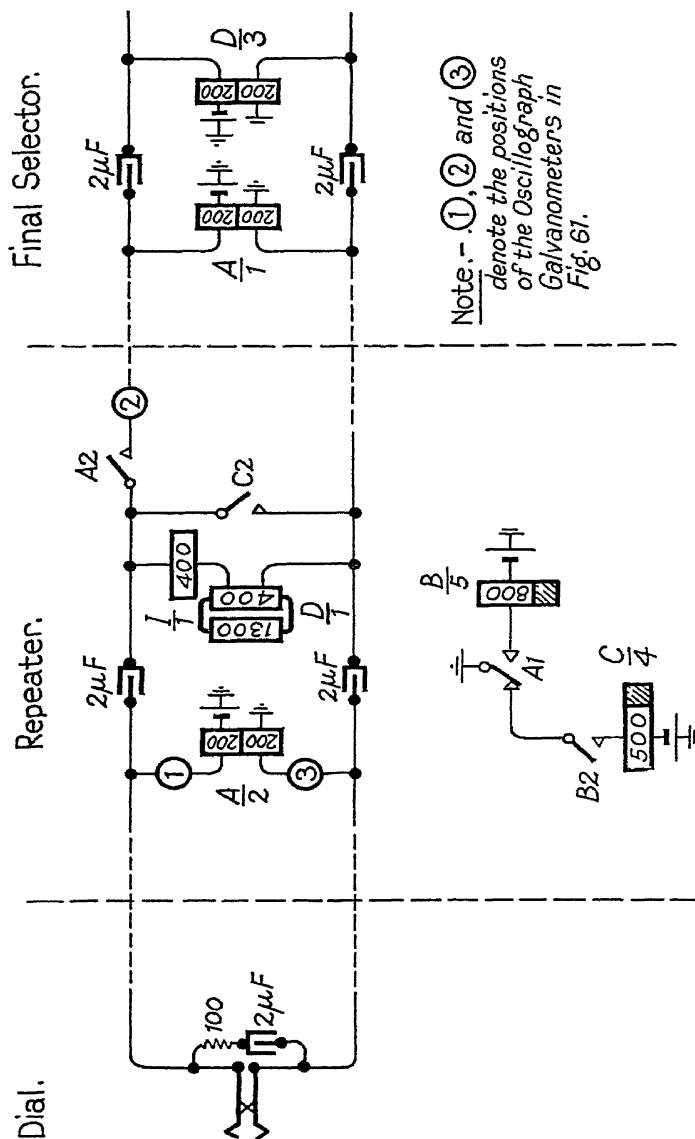


FIG 60. IMPULSING CIRCUIT OF AUTO-AUTO IMPULSE REPEATER

The oscillogram in Fig. 61 shows the performance of the repeater impulsing relay under zero line conditions. The top line (1) and the bottom line (3) represent the currents flowing in the two windings of the *A* relay, whilst the middle line (2) shows the current flowing via the *A2* contact in the negative line of the outgoing junction. The exact position of the oscillograph galvanometers is indicated on the circuit in Fig. 60. In addition, the closing and opening of the dial contacts is represented by continuous and broken lines respectively. An analysis of the surges is given in the following paragraph.

The case under consideration is that of an intermediate impulse, i.e. after the *C2* contact has been operated and has short circuited the high impedance relay. When the dial contacts close (position (*a*) in Fig 61) there is a normal rise of current in both windings of the *A* relay and, so long as the *A2* contacts are open, there is no current in the negative line of the outgoing junction, and the outgoing sides of both transmission condensers are kept at earth potential by the earth feed from the final selector (Fig 60).

When the *A2* contact operates (position (*b*)), it completes the outgoing loop from earth at the final selector to *C2* and *A2* in the repeater and back to the 50 volt battery at the final selector. Thus the potential on the outgoing side of both transmission condensers is raised from zero to the mean between 0 and 50 volts, i.e. 25 volts (negative potential being referred to in all cases, since the positive side of the battery is earthed). This raised potential produces twin surges of current back into the winding of the repeater *A* relay, but the surge in the negative line winding opposes the normal direction of current and that in the positive line winding augments the normal current. This is visible on the oscillogram. From this it might be inferred that the two effects would cancel out, but although the two windings of an impulsing relay are of equal efficiency from the point of view of impedance to speech currents, they are not of equal efficiency as regards operate current, and therefore, if the opposing surge is in the more sensitive instead of in the less sensitive of the two windings, a false release of the *A2* contact takes place as shown by line (2) of the oscillogram.

At position (c) in the oscillogram in Fig. 61 the dial contacts have broken the incoming circuit: the result is a gradual fall of current in both windings of the relay, such as would be expected from an impulsing circuit with a dial condenser and a transmission bridge condenser as well. The

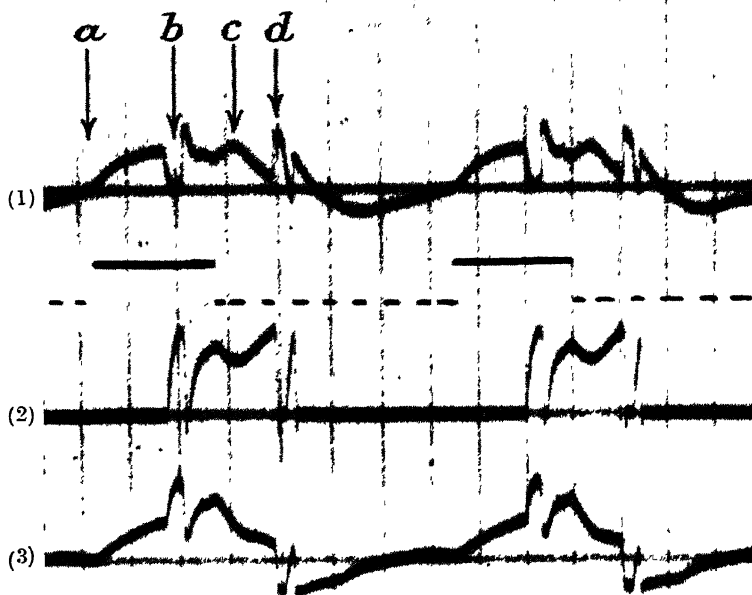


FIG. 61 WAVE FORM IN IMPULSE REPEATER

second junction plays some part, however, in distorting the shape of this portion of the wave form as is shown by the rise in current in line (2) of the oscillogram.

A little later, at position (d), the impulsing relay releases, and the opening of the outgoing circuit at A2 produces twin surges through the transmission condensers in the same way as the operation of A2 considered above, except that the direction of the surge current is the reverse of the previous case. Nevertheless, it is again the negative line

winding which receives the surge tending to produce incorrect operation, and, therefore, the requirement of least sensitivity for the negative line winding holds good for both operation and release.

Even when this requirement is met, there is still a very poor wave form, and if any genuine contact bounce were to occur the effect on the wave form would be amplified. The only real solution to the problem appears to be the disconnection of the transmission condensers during impulsing, thus separating the impulsing circuit of one junction from that of the next, but at present there are other difficulties preventing this step.

It will be noticed also that the *C* relay cannot short circuit the high impedance relay *I* until after the first break impulse has been received, and this results in much more distortion of the first impulse than of the rest. At present, therefore, impulsing via repeaters is not so much a question of short time lags of the impulsing relay as it is a question of the control of condenser surges, and in many cases the relay with the longer operating and releasing lags may give better impulse repetition because it will not respond to the surges.

Compensating Resistance.

In some exchanges, where a repeater is permanently connected to a low resistance line on one side or the other, a compensating resistance is inserted to bring the total loop resistance to a standard figure (between 900 and 1,200 ohms). Thus, all the repeaters are working under the same loop conditions regardless of the actual length of line.

In the case of outgoing repeaters, i.e. repeaters associated with a junction outgoing from the exchange, the compensating resistance is inserted in series with the *C2* contact, which forms the outgoing loop (Fig. 60). Two resistance spools, 300 ohms and 600 ohms, are provided in series and their terminal points are extended to soldering tags, so that either 300 ohms, 600 ohms, or the combined 900 ohms, can be short circuited to give compensation to the nearest 300 ohms. For incoming repeaters permanently associated with a first junction of known resistance, compensating resistance may be inserted in the battery and

earth feeds to the *A* relay, 150 ohm and 300 ohm spools being provided in each feed. The principle in both cases is the same, since the line condition for one of the impulsing relays on the route is stabilized, but, since the greatest distortion is produced by the condenser surges as explained previously, the beneficial effect of compensation is considerably masked, and under some conditions the compensating resistance may produce even greater impulse distortion by aggravating the surges.

Battery Impulsing.

In the preceding paragraphs the remarks have been confined to the principle of "loop impulsing," i.e. impulsing

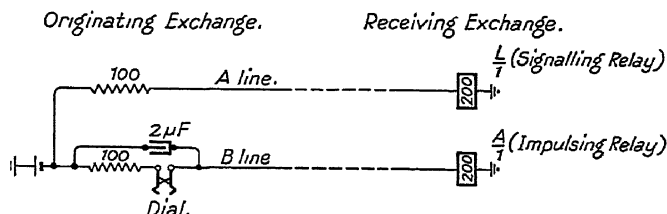


FIG. 62. BATTERY IMPULSING CIRCUIT

by means of a dial at the looped end of a line, in which case both battery and earth terminations of the circuit are in the same exchange and the current must traverse both wires of the junction. For long junctions between exchanges, say, 3,000 ohms loop, and particularly when working from a manual exchange to auto, the "battery impulsing" circuit (commonly called "battery dialling") is frequently employed, the principle being shown in Fig. 62.

In this case the impulses are transmitted on one wire only (termed the *B* line, in accordance with manual exchange practice), the impulsing circuit being from the battery at the originating exchange, via a 100 ohm protective resistance to the dial impulsing contacts, and thence over the *B* line to a single-wound *A* relay connected to earth at the distant receiving exchange. In addition, for signalling purposes, the *A* line is connected from the same battery and a similar 100 ohm protective resistance to a line relay *L* also connected to earth at the distant exchange.

The protective resistances are inserted primarily to reduce the possibility of blowing fuses in the case of accidental earthing, and for low voltage exchanges, e.g. 22 volts, the resistances are reduced to 40 ohms each. A dial condenser is normally fitted and is connected so that the protective resistance has the additional function of preventing the discharge current of the condenser from welding the dial impulsing contacts.

The effect of long lines on battery impulsing relays is approximately half that on loop impulsing relays, because only single line resistance is concerned instead of loop resistance. Moreover, it is usual to adjust battery impulsing relays to a lower operate current in order to assist this effect. Under long line conditions, with a dial condenser, the releasing lag of typical battery impulsing relays is affected less by the maximum flux variation than by the damping of the condenser surge. (See page 124.) As a result, the effect of adding line resistance up to about 400 ohms (equivalent to an 800 ohm loop) is a reduction of break ratio, after which the effect is changed to an increase. This dial variation improves the overall performance under varying loop conditions.

The effect of leaks between lines on short junctions is practically the same as for loop impulsing, because such leaks tend to short circuit the dial contacts. Earth leaks from the *A* line have no effect on the impulsing circuit. Earth leaks from the *B* line are virtually shunted across the impulsing relay, but the effect is very small. It follows that the overall performance of the battery impulsing circuit is particularly suitable for long overhead line construction where leak resistance is more frequently from line to earth than from line to line.

Earth potential difference between the originating and receiving exchanges becomes of importance with battery dialling, and has the effect of increasing the range of voltage within which the *A* relay must carry out its functions, this P.D. is frequently of the order of 3 volts, and may be 7 volts or more in exceptional cases. This is of great importance in cases where the normal battery voltage at the originating manual exchange is low, e.g. 30 volts instead of the 50 volts which is usual for auto exchanges.

Reverted Impulsing.

Another impulsing principle is that known as Reverted Impulse Control, which is adopted in certain systems of automatic telephony, notably the Western Electric Co.'s rotary and panel systems. It may be stated briefly that, when a selector is seized, it is stepped by a machine and the movement of the selector causes impulses to be sent back over the line to the sending end. These impulses are counted automatically and, when the requisite number of impulses has been received, the distant selector is prevented from stepping any farther, having arrived at the outlet required. Although reverted impulsing is used to a large extent in various parts of the world, it is the Strowger system, with either loop or battery impulsing, that is used almost exclusively in this country.

CHAPTER IX

TIME MEASURING INSTRUMENTS

THERE is at the present time a large and varied collection of time measuring devices, both for operating and releasing lags and for impulse ratios and frequencies, and the following instruments have been selected as being representative types*

Oscillograph.

This recording instrument takes first place among time measuring devices, both for normal time lags and for impulsing characteristics, and is, from the telephone engineer's point of view, the standard by which all others are judged. The type of instrument described here is that manufactured by the Cambridge Instrument Co., Ltd., with a few minor alterations which adapt it to the particular needs of relay timing.

Briefly, it may be stated that the current in a relay coil and the current through its contacts are passed through separate reflecting galvanometers, and the changes of current are recorded photographically by means of rays of light reflected from the galvanometer mirrors. The optical system is shown in Fig. 63. The light source is a 24 watt automobile bulb, which is overrun by 100 per cent during the actual exposure. After conversion into three beams by means of a mask in conjunction with the lenses *L1* and *L2*, the rays of light strike the mirrors of the three galvanometers, and finally are focused by *L3* to three spots side by side at the shutter (one only is shown). Immediately behind the shutter is placed the camera, with a drum of sensitized photographic paper ($2\frac{1}{2}$ in. wide), which is passed rapidly in front of the aperture by rotation of the drum. Thus, if the shutter were open and the drum rotated, three parallel straight lines would be traced on the paper, corresponding to the spots from the three galvanometers. If,

* For more detailed information, see "The Measurement of Relay Times" (R. W. Palmer); Inst. P.O. Elec. Engrs. Paper No. 122.

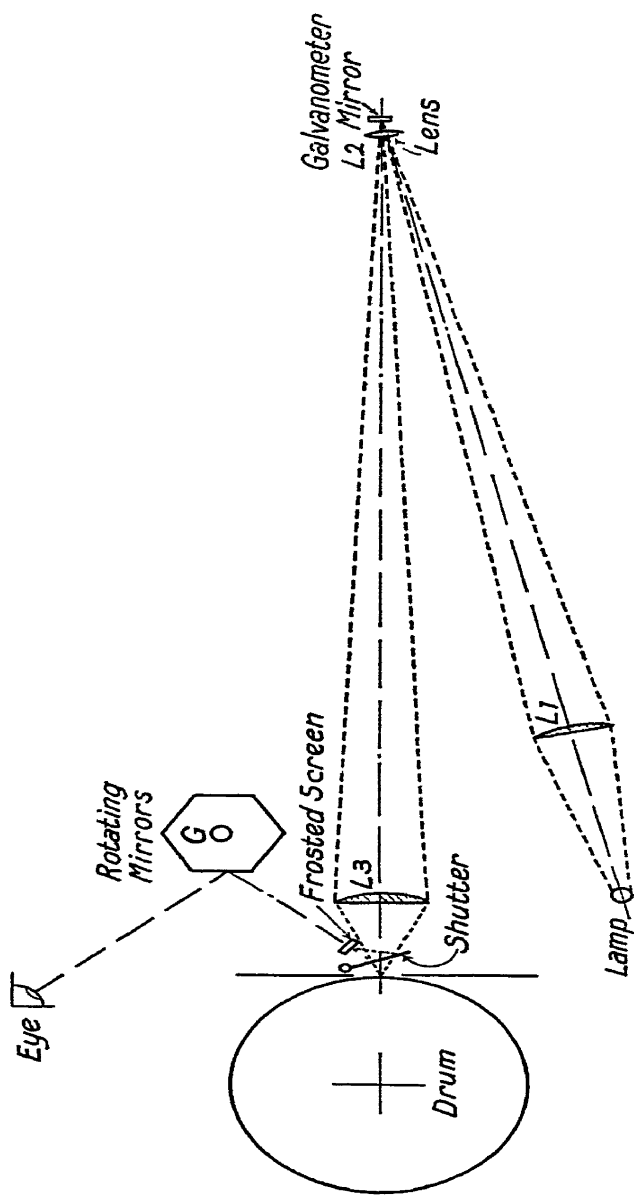


FIG. 63. OSCILLOGRAPH OPTICAL SYSTEM

however, the current in one of the galvanometers changes while the drum is moving, the change will be recorded by a deflection of the corresponding line traced out on the paper.

For the measurement of the time lag of a relay at two make contacts, one of which is an x contact, the current in the coil is passed through No. 1 galvanometer, the x contact is connected in series with the No. 2 galvanometer, and the last contact is connected in series with

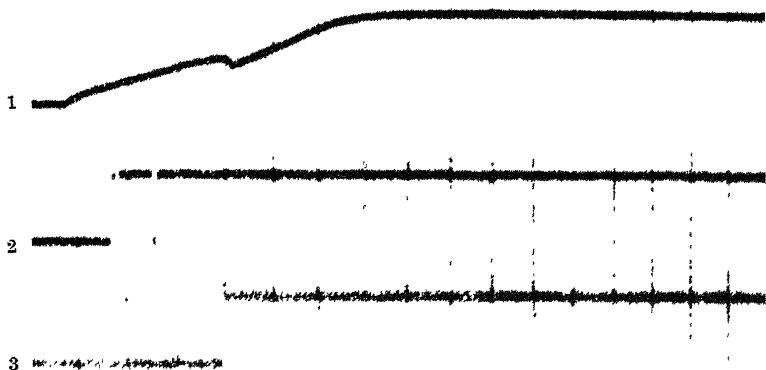


FIG. 64 OSCILLOGRAM OF RELAY OPERATION

the No. 3 galvanometer. In each case suitable values of shunt and series resistance are used to give a reasonable deflection without interfering with the circuit conditions under which the relay is being tested. The result of taking an "oscillogram" of such a relay is shown in Fig. 64. The shape of the deflections in the top line shows the gradual rise of current in the relay coil when it is energized, whilst in the second line, although the current rises to its maximum instantaneously, there is some bounce of the contacts, which causes momentary disconnections of the current. The third line shows a clean contact being made without bounce.

The vertical lines are also made photographically and are 10 mS. apart in time relationship, being produced by a separate shutter actuated by a tuning fork. This fork has an accuracy of 0.01 per cent by National Physical Laboratory test, and gives a flood of light across the normal aperture every 10 mS. The paper can be moved so quickly that these vertical timing lines are as much as $\frac{1}{2}$ in. apart, and thus it is an easy matter to determine the operating lag of the relay by counting up the number of 10 mS. spaces, or fractions of spaces, between the commencement of the current in the coil and the change of current produced by the contact. An alternative to the use of timing lines is the passing of an oscillatory current of known frequency through one of the galvanometers, but for obvious reasons this is not so satisfactory.

In Fig. 64 the operating lag of the x contact is 11 mS. (including the worst portion of the bounce), and that of the other contact is 33 mS. The armature is not fully attracted until 2 mS. later, this being indicated by the deflection of the top line because, when the armature strikes the core, the reluctance is reduced rapidly and this produces a back E.M.F., which shows itself as a momentary reduction of the current in the coil.

A "transportable" oscillograph is shown in Fig. 65. The apparatus can be packed away in the box, which, when measurements are being carried out, forms a table. The legs can be unscrewed and fitted inside the box, and the spare parts, photographic materials, developer, etc., are carried in a leather case specially fitted up for the purpose. In the illustration, the spare galvanometers in the carrying case are clearly shown; they have horse-shoe permanent magnets for the production of the field, and the movement consists of a single loop of fine wire, which also forms the bifilar suspension. The moving parts are enclosed in a sealed chamber filled with damping oil to prevent over-deflection. A diminutive mirror, approximately $\frac{1}{12}$ inch in diameter, is secured to the suspension in a position immediately behind a window between the poles of the magnet, and levelling screws are provided for adjustment of the rays of light. These galvanometers are not so sensitive as those used for high frequency work, a current of 30 mA.

being required to give a deflection of 1 cm. on the oscillograph paper, but this is sufficient for most needs and

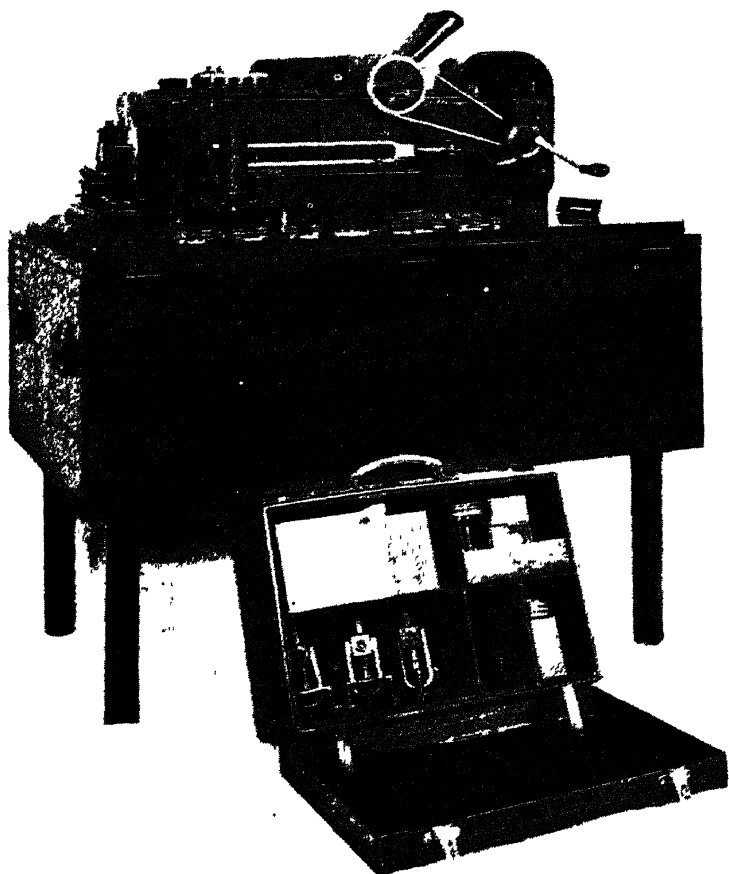


FIG. 65. PORTABLE OSCILLOGRAPH

enables a very compact and portable instrument to be produced. On the oscillograph illustrated some galvanometers are in position on the left-hand side, the camera being seen as a rectangular box at the opposite end. In

this case the paper is rotated by turning a handle, but in stationary oscillographs an electric motor is used, giving a more even speed so that the 10 mS. timing lines are more evenly spaced

The camera shown is not of the single drum type which was mentioned previously, but of the cinematograph film type, allowing as much as 150 feet of oscillograms to be taken, either in sections or as one long record. It should be mentioned, however, that in the drum type of camera, a series of cams is employed whereby the shutter is opened for $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, or the whole of one complete revolution of the drum, which is 10 inches in circumference, and, provided that care is exercised in synchronizing the relay operation with the exposure, the drum camera is more economical in paper. This synchronzation can be facilitated by making the opening of the shutter close or open the circuit of the relay under test. Either camera may be jacked in or out with great ease, its case being rendered light-tight automatically as soon as it is removed from the oscillograph.

The eyepiece seen protruding from the top of the oscillograph is used for observing the deflection of the rays of light before the photographic record is actually taken, this being achieved by a system of rotating mirrors driven by a belt from the camera spindle (Fig. 63). On the baseboard are terminals, low resistance variable shunts for the galvanometers, and other apparatus for the control of the circuits.

There are other types of oscillograph which are suited to relay work, and which give more facilities than the instrument just described; for example, the Siemens and Halske instrument and that of the International Western Electric Co., the former having seven and the latter six galvanometers, but a detailed description of the many ingenious devices that they contain is not necessary in this book

Other Recording Instruments.

There are a number of other devices for recording the operation of relays, most of them involving an ink or pencil mark on a moving strip of paper. They are not, as a rule, suitable for telephone work, except for very slow

relays, chiefly because of the difficulty of obtaining a clear record at high paper speeds; about 10 in. per second is the maximum. Records can be made more easily by means of a stylus on a celluloid strip, as in the Cambridge Instrument Co.'s chronograph, and since the line produced will stand examination by microscope, a much greater accuracy can be obtained. The limitation of many of these recording

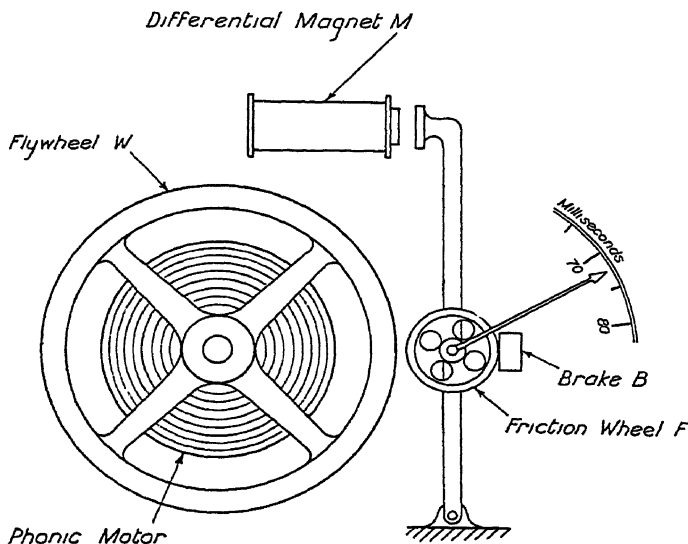


FIG. 66. PHONIC CHRONOMETER PRINCIPLE

instruments is, however, the comparatively large amount of power required to operate the "pen" or stylus.

Electrical Chronometers.

There are very few electro-mechanical indicating instruments suitable for telephone relay work, chiefly because of inertia effects, preventing the measurement of small time intervals. One which has been used with some success for slow relays is the phonic chronometer, made by Messrs. Tinsley & Co. and shown in principle in Fig. 66. The essential part is a phonic motor, which is driven at constant speed by an electrically maintained tuning fork. The

flywheel of the motor is represented by the large wheel W in the diagram, and, situated within a few mils of this wheel, is a smaller friction wheel F , which can be brought into contact by means of the magnet M . The spindle of the friction wheel is extended to carry a light pointer, which moves over a dial suitably graduated to give a direct reading of the period of contact between the wheels. In

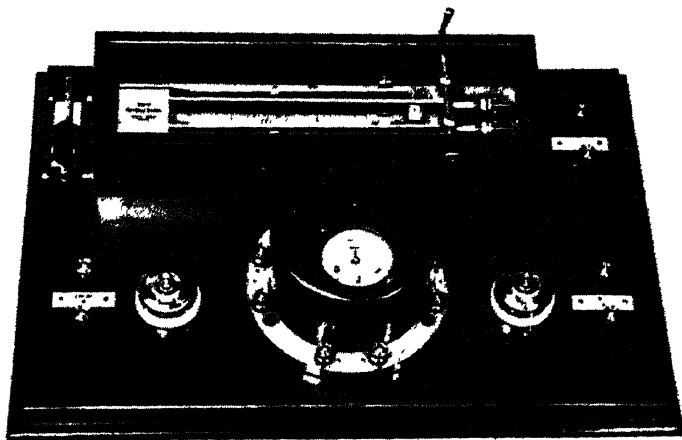


FIG. 67. PHONIC CHRONOMETER TIMING SET

the normal position the friction wheel rests against a back-stop, which also acts as a brake to arrest the rotation of the wheel when the magnet M is released. The electro-magnet M has two coils differentially wound; they are connected so that when the currents are flowing in opposite directions the fluxes produced cancel each other, and the friction wheel is allowed to remain against the back-stop. When one of the differentially wound coils is disconnected, the magnet operates and starts the rotation of the pointer: then, when the other coil is disconnected, the magnet is released and the pointer is immediately arrested by the brake. The instrument will also measure the period between the times of energizing of the two coils.

Attention has been paid to the reduction of errors resulting from slip and inertia of the friction wheel and pointer, eccentricity of wheels, magnet time lags, residual flux, etc., and to this end the travel of the magnet armature has been reduced to 5 mils. Instead of a single dial and pointer, the instrument made by Messrs. Tinsley & Co., and illustrated in Fig. 67, has a simple train of four dials giving readings up to 100 seconds, the pointer being re-set by hand between successive tests.

A chronometer of this type is also made by Messrs. Everett Edgcumbe, Ltd., the motor in this case being a Warren synchronous motor driven from A.C. mains, but both instruments are suitable only for relays with time lags in excess of about 100 mS.

Ballistic Galvanometer Methods.

There are two ways of measuring time intervals with a ballistic galvanometer, the first of which makes use of the time constant of a circuit containing capacity and resistance. The ballistic galvanometer is used to measure the charge acquired by the condenser, during the time that the test relay is operating, and this time can be calculated as follows—

In a circuit containing capacity C and resistance R , and a constant applied voltage V , the relation between the current I and the time t is given by—

$$V = IR + \frac{1}{C} \int I \cdot dt$$

from which it may be found that, when a condenser is being initially charged, the relation between the charge q , acquired during the time t , and the ultimate charge Q , which would be acquired after an infinite time interval, is given by—

$$q = Q (1 - e^{-t/RC})$$

$$\text{hence} \quad \frac{t}{RC} = -\log_e \frac{(Q - q)}{(Q)}$$

$$\text{and} \quad t = -RC \log_e \frac{(Q - q)}{(Q)}$$

This gives an expression for the time interval during which the condenser has been charged, the values of the quantities

Q and q being proportional to the deflections of the ballistic galvanometer in the condenser circuit. If, therefore, the capacity C of the condenser is measured in farads, and the total resistance R in series with it (including that of the galvanometer) is in ohms, the time t in seconds can be calculated from the ratio of the galvanometer deflections.

It is sometimes more convenient, however, to use the discharge of a condenser, in which case the same formula will apply, if for q we insert the amount of the discharge instead of the charge. It can be shown also that the maximum sensitivity is attained when the time $t = RC$, the ratio $\frac{C}{R}$ being as great as possible. Since these methods

depend on fundamental calculations from first principles, they have been used as a check on others which have less accurate speed controlling devices.

An alternative method of using a ballistic galvanometer is to pass a known current through it for the time t , the throw obtained being a direct measure of this time. This lends itself to very accurate measurements and has been used for time intervals from a small fraction of a milli-second up to 1,200 mS.

In all cases special attention is paid to the simultaneous closing of the test relay and the galvanometer circuits. Two separate fast operating relays may be used, being energized by the same starting current, in which case they can be adjusted by varying resistances in series with them. In this way the operation of the two circuits can be synchronized to one-twentieth of a millisecond, and in special cases to one-hundredth of a millisecond.

Electrostatic Voltmeter Method.

This is a condenser charge method similar to the ballistic galvanometer instrument, but here, instead of measuring the charge, the potential acquired by the condenser is measured by means of an electrostatic voltmeter. The formula in this case is, therefore—

$$t = -RC \log_e \frac{(V - v)}{(V)}$$

where V is the applied voltage and v the potential acquired

by the condenser. The maximum sensitivity is when $t = RC$, independently of the magnitude of C . A convenient circuit is that shown in principle in Fig. 68, from which it will be seen that the voltmeter reads " $V - v$ " direct. Two auxiliary relays, SA and SZ , are used to start and stop the charging of the condenser, but, provided that their operating lags are equal, they do not affect the reading.

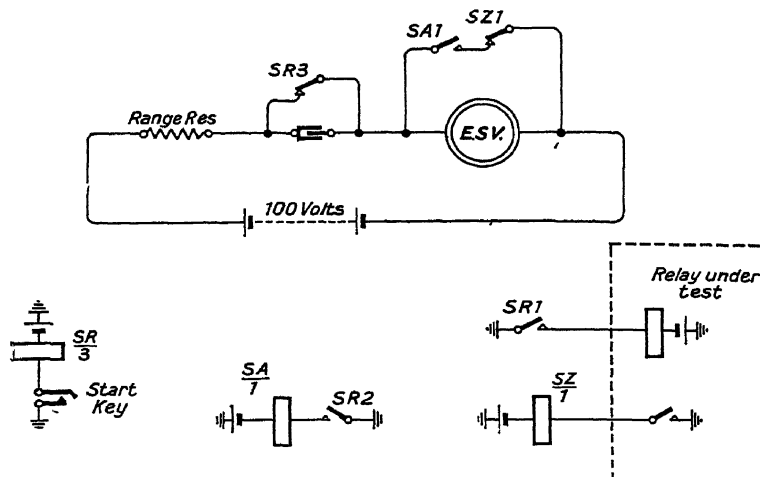


FIG. 68. ELECTROSTATIC VOLTMETER TIMING CIRCUIT

Millisecond Meter.

In this time measuring device the interval is measured on an instrument differing very little from an ordinary milliammeter, and therefore it may be made in portable form (Fig. 69). The millisecond meter is a patent of Messrs. Siemens Bros. & Co., Ltd., and was designed by Mr. Grinstead of that company.

In an ordinary moving coil instrument the speed at which the pointer takes up its position when the current is applied is dependent upon—

- (a) The deflecting force due to the current in the coil.
- (b) The controlling force exerted by the restoring spring.
- (c) The damping force.
- (d) The inertia of the moving system.

If, however, the restoring spring is removed entirely, and

the damping force is made very large compared with the inertia, the deflecting force due to the current will cause the pointer to move over the scale with a constant speed which will be proportional to the value of that current.

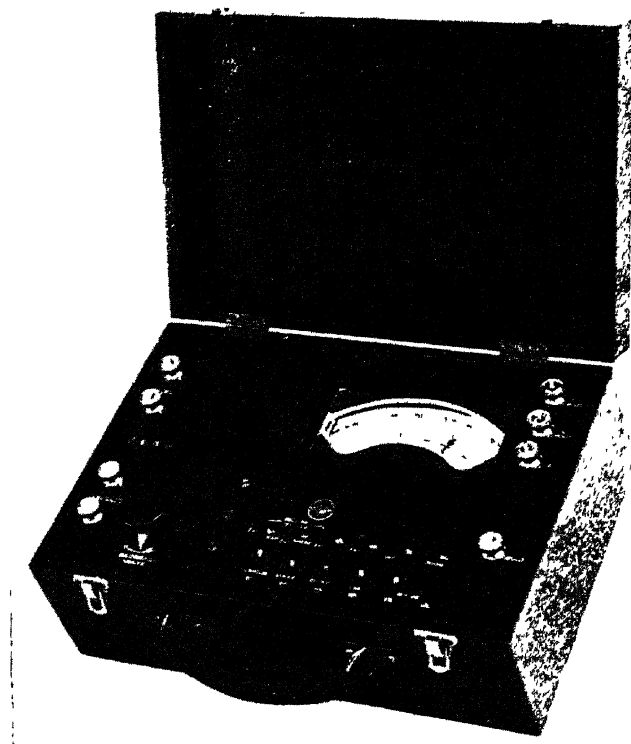


FIG. 69. MILLISECOND METER

and to come to rest quickly when the current is cut off. Thus, by applying a known current for a short interval of time the ultimate deflection of the pointer will be a direct measure of that time. Moreover, since there is no restoring force, the pointer will remain in position until returned to zero by a reverse current.

With the fundamental arrangement as described, the deflection is directly proportional to the time interval, and therefore, if the current were applied for an excessive time, the pointer would be forced against the stop at the end of the scale and possibly would be damaged. This can be remedied for relay work by using the discharge current of a condenser in place of a steady current, and this method is shown in Fig. 70, which is a circuit diagram of a complete timing set for the measurement of relay lags.

It will be seen that the $20\mu\text{F}$. condenser is normally at a potential determined by the position of the potentiometer. The start key *ST* is thrown, and then, in the case of an operating lag, relay *SA* simultaneously energizes the test relay and completes a discharge circuit for the condenser via the resistances and the millisecond meter. As soon as the test relay contacts close, the millisecond meter is short circuited and the pointer is, therefore, immediately brought to rest. After the reading has been taken, the re-set key *RS* is operated, thus giving the meter a small reverse current, which gently restores the pointer to the zero position.

This arrangement gives a logarithmic scale, and the capacity of the condenser can be such that the current resulting from the complete discharge will not move the pointer beyond the full scale deflection. It will be seen from this circuit that all relay testing requirements can be met without introducing the time lags of auxiliary relays, but one relay is still required to provide simultaneous operation of the test relay and the meter. Since the deflections in this instrument are dependent on the voltage at the time of the test, the potentiometer is adjusted until a full scale deflection is given for an infinite time interval; that is to say, for the complete discharge of the condenser. It is arranged that this may be done quickly by means of a "check" key.

The millisecond meter can also be arranged to test impulse ratio and frequency, by measuring first the time taken for a train of impulses and then the sum of the make or the break periods in that train.

As regards accuracy, provided the voltage is constant throughout the test, readings of 500 mS. can be obtained to within 1.5 per cent, whilst the errors on small times of

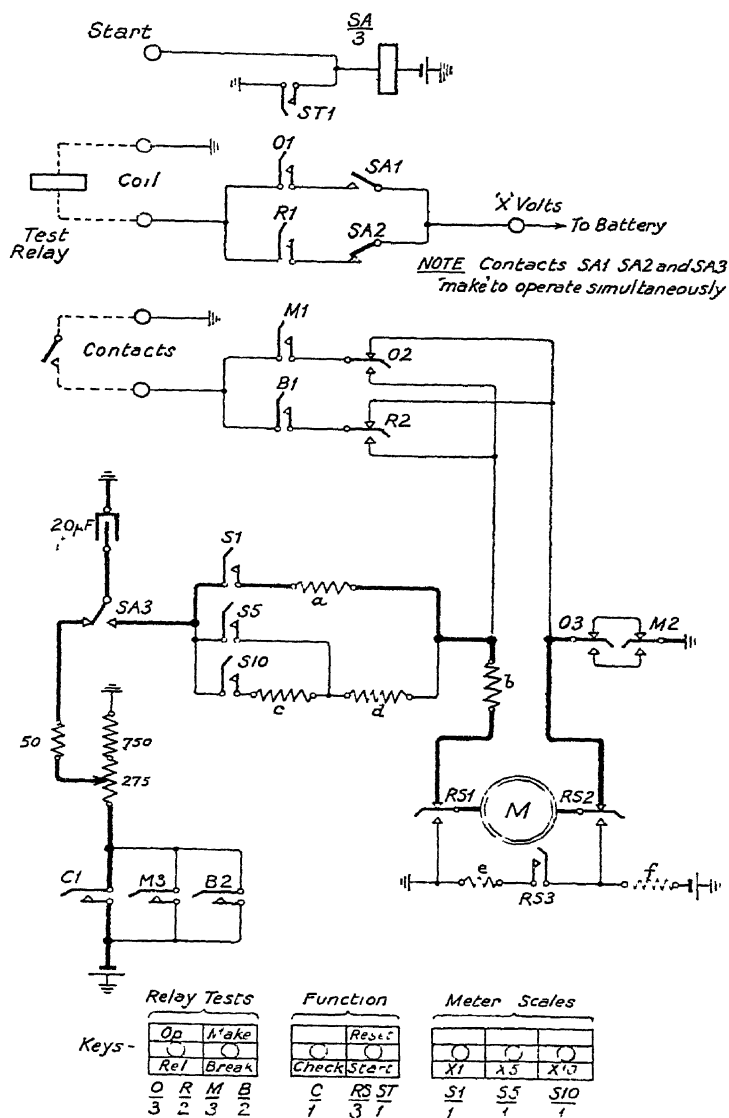


FIG. 70. MILLISECOND METER CIRCUIT

25 mS. down to 1 mS are too small to be detected by the oscillograph.

Variable Interrupter Method.

This is a null method of measuring relay lags, and is one of the few instruments which can be used for the determination of pulse-operating times. The variable interrupter

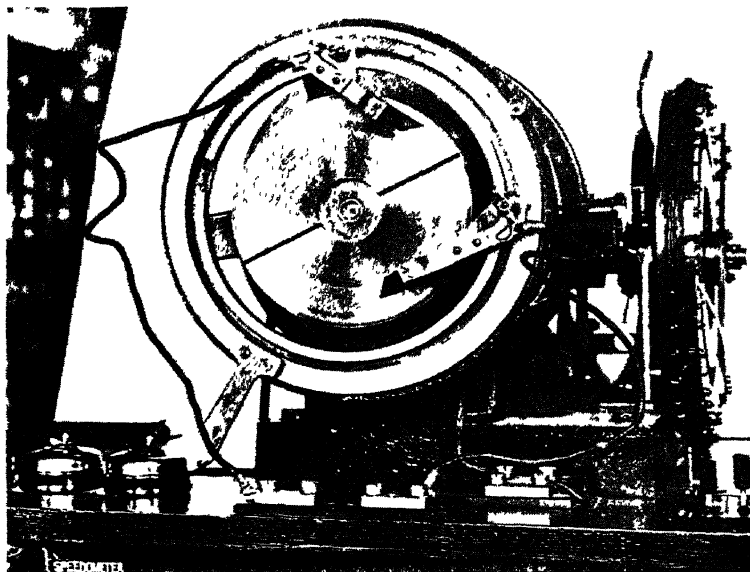


FIG. 71. VARIABLE INTERRUPTER

is the same as a variable impulse machine, except that there is a much greater range of adjustment than is required for impulsing work. There are many types of instrument which will provide this facility: for example, the Helical Commutator with brushes that move along the axis, the ordinary Drum Commutator with brushes which can be rotated about the axis, and the Disc Commutator of a similar type; but in explaining the general principles reference will be made to the disc instrument used by Messrs. Siemens and shown in Fig. 71. The commutator disc is

divided into two segments, and the two brushes in their adjustable mounting are shown clearly in the photograph. When the disc is rotated by an electric motor, current will pass between the brushes so long as those brushes are resting on the same segments, and, therefore, the length of make is dependent on the angular displacement of the brushes. The brush mounting is calibrated in degrees for this purpose. The length of make is also dependent on the speed of the disc, so provision is made for indicating the speed, either by means of a mechanical tachometer or, as in the Siemens case, by measuring the voltage from a low tension magneto connected to the shaft.

Pulse-operating times are measured by connecting the test relay in series with the commutator, the length of the "make" being adjusted until the relay just operates, as indicated either by visual observation or by listening in a telephone receiver connected to the relay contacts; the break period must be kept sufficiently long for the flux in the relay to drop to zero between successive operations. The displacement of the brushes is then a measure of the "pulse-operating" lag. Releasing lags may be measured in a similar manner.

Ordinary operating and releasing times require the use of two commutators on the same shaft, as shown in Fig. 72. Here the relay under test *R* is connected as before in series with one commutator *A*, but the other commutator *B*, with its brushes in the opposite phase, is connected in parallel with the test relay contacts in the circuit of a telephone receiver. The speed of the shaft and the position of the brushes on disc *A* are first adjusted so that there is ample time for the relay *R* to operate; in the positions shown, the *A* disc will have just energized the test relay. At the same time the *B* disc will have given a click in the receiver, followed by another click after the lapse of a few milliseconds when the test contacts *R1* close. The brush *B1* can be moved in the direction of rotation until the two clicks coincide, and then the angular displacement of *B1* with respect to *A1* is a measure of the operating lag.

Releasing lags are measured similarly except that, in order to avoid confusion, the operating clicks must be made to coincide first. The brush *B2* is moved in the

direction of rotation until double "release" clicks commence. Further slight adjustment enables the point of coincidence to be found and then the angular displacement of *B2* represents the releasing lag of the test relay.

The accuracy of this method depends almost entirely on the mechanical design of the machine in such details as rigidity of brushes, width of brush contacts, speed regulation, etc., and, in any case, since it is a null method, it has

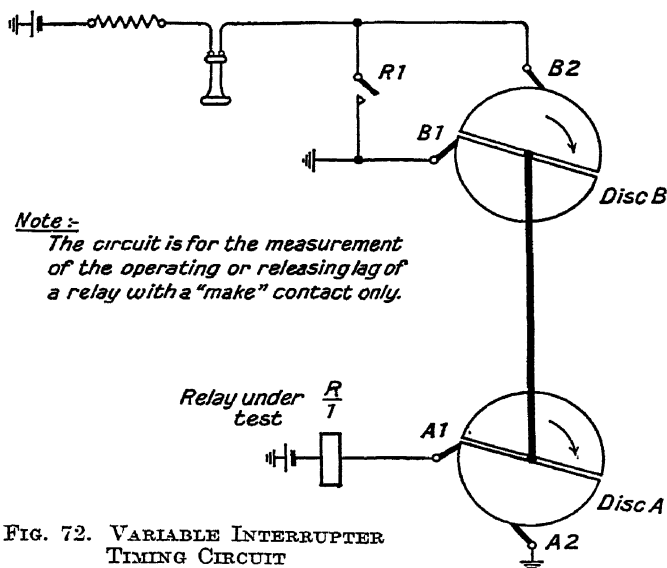


FIG. 72. VARIABLE INTERRUPTER TIMING CIRCUIT

to be assumed that the characteristics of the relay are consistent in successive tests.

Condenser Bridge Method.

There are many variations and adaptations of the well-known Wheatstone bridge principle, the ordinary capacity bridge being one which is in common use, but there is a new variation of the capacity bridge which has been developed by the American Telephone & Telegraph Co. of the United States.*

* See "Bridge for Measuring Small Time Intervals" (J. Herman); *Bell System Tech. Jnl.* Vol. VII, 2; April, 1928.

The principle of the condenser bridge timing set is shown in Fig. 73, where the operating lag of a relay with a make contact is being measured. When the start key is thrown the *SA* relay operates so that *SA1* energizes the relay under test, whilst *SA2* completes the charging circuit for the condenser *C1* in one arm of the bridge via the variable resistances *R1*. The smaller condenser *C2* in the other arm of the bridge is already charged to the full battery potential. The condenser *C1* continues to be charged

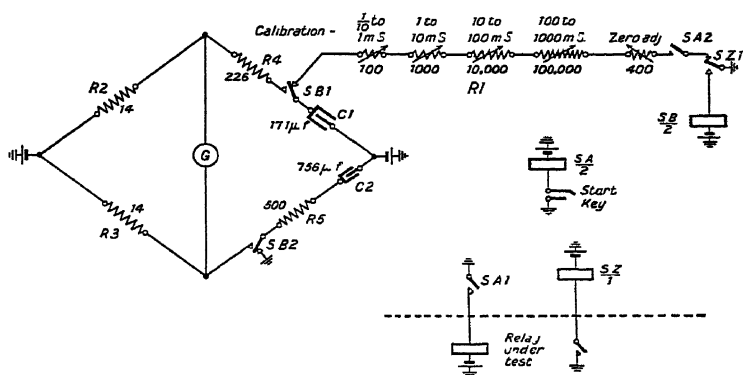


FIG. 73. CONDENSER BRIDGE TIMING CIRCUIT

until the test relay contacts close and operate the "stopping relay" *SZ*. The *SZ* contacts disconnect the charging circuit and then operate the relief relay *SB*, which closes the condenser arms of the bridge circuit. Thus, if the charge acquired by the large condenser *C1* during the time *t* is equal to the full charge of the smaller condenser *C2*, then the bridge will be balanced as indicated by zero deflection on the galvanometer. The value of the time interval *t* will be obtained from the formula—

$$t = -R1 \times C1 \times \log_e \frac{(Q - q)}{(Q)}$$

In this case, however, *q* is a constant and is equal to the full charge of the condenser *C1*, and *q* is also a constant and equal to the full charge of the condenser *C2*, this being

equal, under balanced conditions, to the charge acquired by the condenser $C1$ during the time t . Hence, the time is directly proportional to resistance, and, if suitable values for $C1$ and $C2$ are chosen, the readings of $R1$ in, say, hundreds of ohms, can be made a direct measure of the time in milliseconds. It will be noted that there are additional resistances $R4$ and $R5$ included in the discharge circuit of the condensers. These are to prevent sparking at the SB contacts, but if double kicks on the galvanometer are to be avoided it is essential that the time constant of the discharge circuits should be the same, and the values of these resistances must be chosen such that—

$$\frac{R2 + R4}{R3 + R5} = \frac{C2}{C1}$$

A standard 4-dial decade resistance box may be used for the variable resistance $R2$, and may be calibrated from $\frac{1}{10}$ mS. to 1,000 mS. in $\frac{1}{10}$ mS. steps. In series with $R1$ will be seen a zero adjusting resistance $R6$, which compensates for the lag introduced by the relays SZ and SB . A suitable galvanometer is the Weston flush-pattern needle instrument.

For the accuracy of such a set as this one has but to consider the supremacy of other types of bridge circuit in this respect, the only requirement being the use of high grade resistances and condensers. The maximum sensitivity will be obtained with high voltage, large condensers, and high capacity ratio. It will be noted, however, that a constant voltage is necessary, although for telephone exchange work a potentiometer could be provided for this purpose.

Metroscope.

The timing devices so far described have indicated that the measurement of relay lags has become almost as simple as the measurement of relay operate or release currents, but in nearly every case there is the difficulty that access to the contacts must be given as well as access to the coil of the relay. It was with a view to eliminating these difficulties that an optical instrument called the Metroscope (Fig. 74) was designed by the author.

The fundamental principle is that of a photographic shutter giving various exposures, so that if the relay is

energized when the shutter is opened the exposure can be adjusted until there is just time to see the contacts move when looking through the aperture. The latest metroscopes differ from this in that the shutter is normally open, enabling the observer to get his eye well focused on the relay contacts before making a test. The relay is energized by the operation of the start button, and, after the requisite time interval, the shutter closes, cutting off the view. The wheel on the left (Fig. 74) controls the speed of the shutter

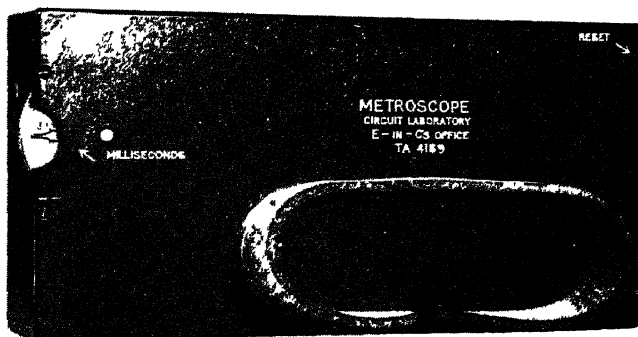


FIG. 74 METROSCOPE

and is calibrated direct in milliseconds.* The starting and re-set controls are also indicated.

Fig. 75 shows the internal mechanism. The speed of the shutter is regulated by an air piston with spiral spring drive and needle valve control. The piston is a machined fit in its cylinder, and a universal joint is provided between piston and piston rod. In the upper photograph the piston rod, situated just below the lamp has been pulled to the right by the "re-set" lever, and this lever has returned to its normal position to avoid interference with subsequent operations; the double vane shutter in the right-hand lower corner is open. The contacts in the centre for operating or

* NOTE.—In Figs 74 and 75 the control wheel shown is calibrated in degrees for experimental purposes.

releasing the relay under test are relay springs of the make-before-break type, and a small two-way switch protruding through the lower edge of the case is used to select either the make or the break portions of the assembly, according

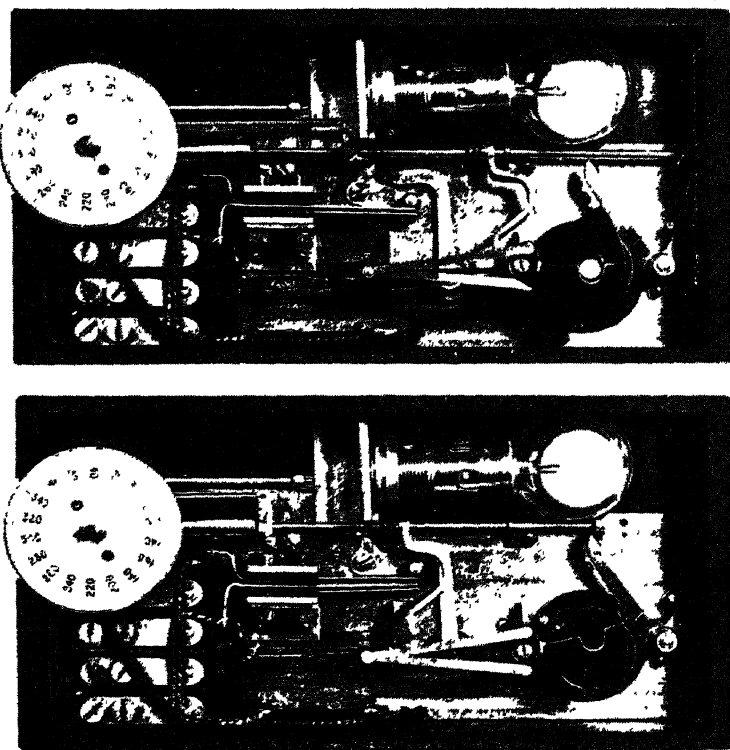


FIG. 75. METROSCOPE MECHANISM

to the type of test that is required, i.e. operating lag or releasing lag. When the start button on the left-hand side is pressed, a trigger is released and the piston rod moves to the left at a speed dependent on the setting of the valve control, and, early in its stroke, it allows the contacts to make or break as the case may be. The shutter remains

open until released by a trigger at the end of the stroke of the piston, the speed of closing being such as to give an almost instantaneous cut-off independent of the speed of the piston. The lower photograph shows the shutter closed at the conclusion of a test.

Other facilities provided in the metroscope illustrated are the illumination of the relay under observation by means of the small 10-watt lamp, and the provision of a 4-point jack and plug of the "operators' telephone" type, for making rapid connection to the control contacts and to the lamp.

With an optical instrument the errors are necessarily dependent on the individual, and owing to the limitations of the human eye it is difficult to time relays with lags of less than 25 mS. with great accuracy. A time lag of 300 mS., however, may be measured after very little practice to within 20 mS.; it is doubtful if much greater accuracy than this would be obtained even with greater precision in the mechanism, because of the appreciable time taken for a relay armature to move. This difficulty is, of course, more pronounced in the case of operating lags, and, for this reason, it is best to observe on one particular relay contact rather than on the armature. The maximum range is of the order of 1,000 mS.

Uniselector Method.

Any of the direct reading instruments could be used for checking that the lag of a relay was within a certain range, especially those incorporating null methods, but the uniselector method is one of a class which is used only to check a range of time accurately, without providing details of the exact time lag. It has been included in certain automatic routiner circuits in telephone exchanges. A skeleton circuit for the measurement of selector *B* relay releasing times is shown in Fig 76

It consists of a uniselector connected by a relay contact or by a start key to the exchange impulse machine running at 20 impulses per second. After the uniselector has taken the first step the wipers on No 1 bank disconnect the relay under test. The switch continues stepping at 50 mS per step, and the circuit is so arranged that if the relay releases

whilst the wipers are on certain contacts representing a predetermined time margin, the routiner is stepped on to the next test. If the relay is too fast or too slow, the uniselector wipers will have reached different positions and lamp signals will be given accordingly. Many refinements are

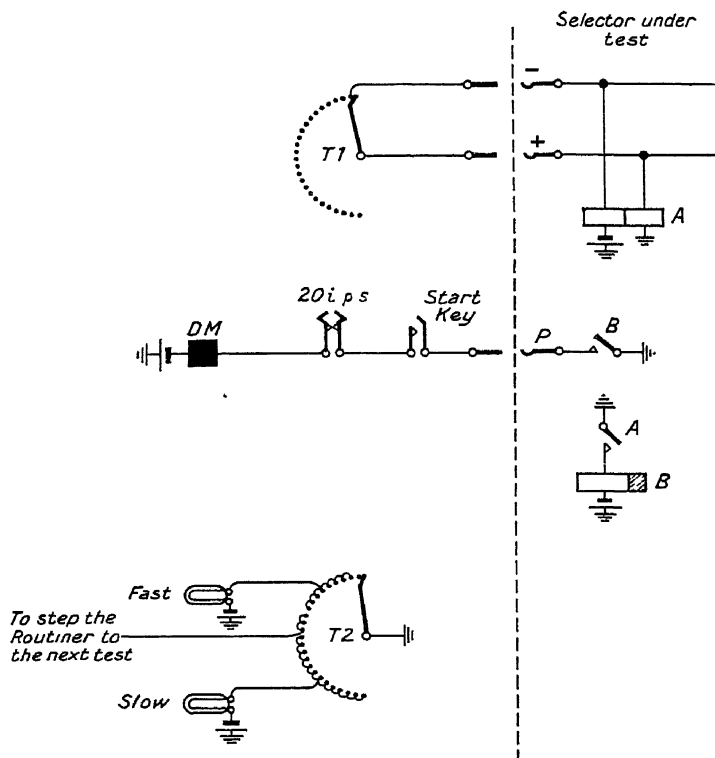


FIG. 76 UNISELECTOR TIMING CIRCUIT

required in a circuit of this kind, but the important point is that the release (or operation) of the test relay must be effected by the uniselector itself after it has commenced stepping. So long as this is done, any time margin can be checked in steps of 50 mS. with an accuracy which is dependent almost entirely on the frequency reliability of the

exchange impulse machine. The present frequency variation on these machines is ± 5 per cent, but in any case the actual frequency can be checked by allowing the uniselector to rotate continuously, the time taken for a number of revolutions being measured by means of a stop watch. Although the time readings are in steps of 50 mS., the first step is usually about 20 mS. instead of 50, being dependent on the ratio of the impulse machine and the time lags of the uniselector magnet; the actual value can be calculated. A transformer on a supply company's A.C. mains can also be used for driving the uniselector, since the frequency is usually kept within very narrow limits.

There are also other methods of checking relay lags by comparison with constant time intervals, e.g. using pendulums, calibrated relays, etc., but these are rarely used by the telephone engineer.

Milliammeter Ratio Tester.

This type of instrument is particularly suited to the measurement of impulse distortion by relays, and was first developed by the Research Section of the G.P.O. Engineering Department, it may be adapted also to the measurement of operating and releasing lags under impulsing conditions.* The method depends on the fact that a heavily damped milliammeter in series with, or shunted by, an impulsing contact gives a reading which is proportional to the make or break ratio of the impulses. A suitable instrument is a specially damped Unipivot milliammeter (0–120 mA.), made by the Cambridge Instrument Co. In Fig. 77 the relay under test is shown at *A*, connected to an impulsing circuit. Immediately below it at (*a*) is shown the skeleton circuit of the tester when arranged for the measurement of break ratios. The milliammeter is normally in series with a battery and a variable resistance *R*, which limits the current to 100 mA. When impulses are being received the meter is short-circuited during each operation of the make contact *A1* of the relay under test, and current is allowed to flow only for the duration of the break periods.

* See "The Distortion of Dialling Impulses" (L. H. Harris); *P.O. Elec. Engrs. Jnl.*, Vol. XVII, Part 4; January, 1925.

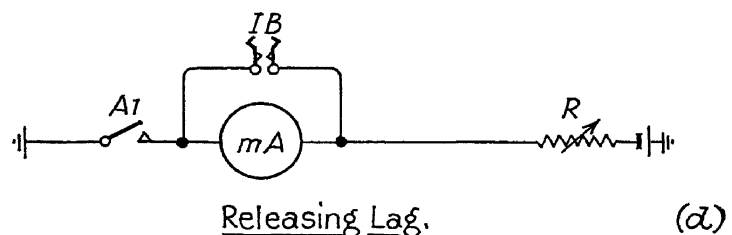
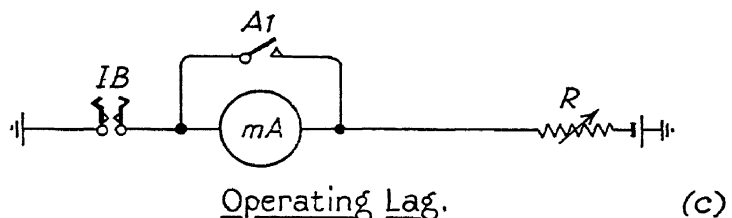
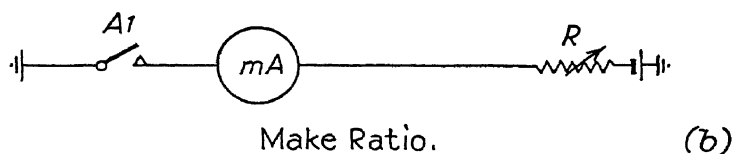
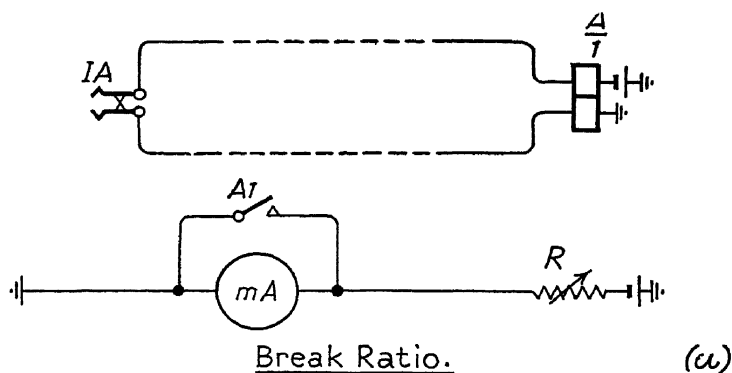


FIG. 77. MILLIAMMETER RATIO TESTER CIRCUITS

Hence, the reading in milliamperes will express the percentage break given by the *A1* make contacts.

The next circuit (*b*) shows the *A* contacts in series with the milliammeter instead of in parallel, and, therefore, current passes only during the make periods, and the reading in milliamperes consequently expresses the percentage make ratio. Similar circuits may be devised for the measurement of the break or make ratio given by the break contacts, but for tests on A.T.M. relays the use of the break is undesirable because of the possibility of bounce on that contact.

For the measurement of the operating lag of an *A* relay under impulsing conditions the circuit (*c*) is used. It is necessary to have a duplicate set of impulsing contacts *IB*, which operate in exact synchronism with the impulsing contacts *IA*, which are operating the *A* relay. It is convenient in most circumstances to use two repeating relays controlled by a common impulse machine, one with make contacts which carry out the function of *IA*, and the other for *IB*, because then the synchronization can be effected by varying resistances in series with the respective repeating relays until they both give zero, or at least equal, distortion. In the circuit (*c*) the *IB* contacts are in series with the milliammeter and the *A1* contacts under test are in parallel. When the *IA* and *IB* contacts close the *A* relay is energized, and, simultaneously, current is passed through the milliammeter. Later, after the operating lag of the *A* relay has elapsed, the meter is short circuited by *A1*, and since, at the end of the make impulse, the *IB* contacts open before the *A1* contacts are released, there will be no further current in the milliammeter except during each subsequent operating lag of *A*. Consequently, the reading on the meter is the measure of that operating lag.

The circuit (*d*) is similar in principle, except that the *IB* and *A1* contacts are transposed, and it will be seen that current passes through the milliammeter only during the interval between the opening of *IB* and the opening of *A1*, this time interval being the releasing lag of the *A* relay under impulsing conditions.

Facilities may be provided for making rapid changes from one type of circuit to another, and for testing the

ratio of short trains of impulses such as are given by subscribers' dials. In this case it is desirable to arrange by means of slow relays that, prior to the test, the milliammeter shall give a reading equal to the ratio which is expected from the dial. Then, when the impulses commence,

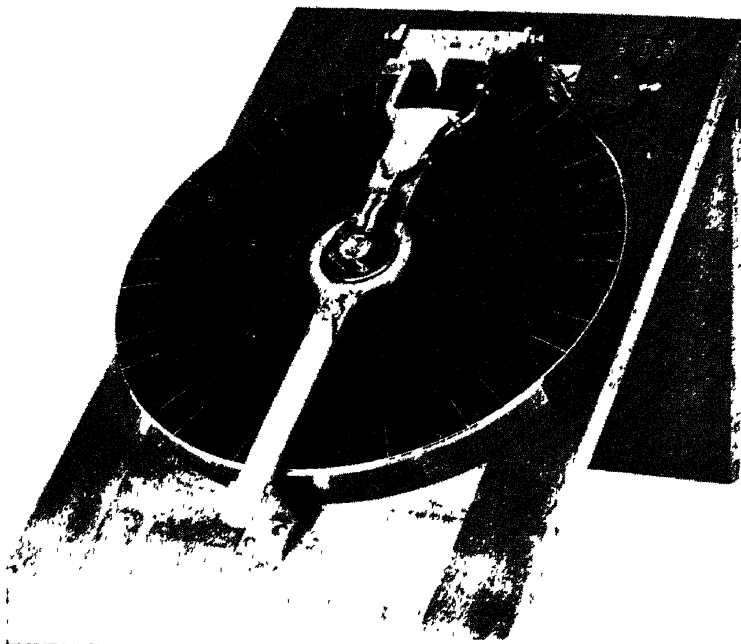


FIG. 78. DISC RATIO TESTER

the needle of the dial has less distance to travel than it would have if the initial reading were either 100 per cent or 0 and, as a result, a steady reading is reached more rapidly. In fact, the most accurate method of measuring dial ratio is by varying this initial reading of the milliammeter during the test until there is no movement at all when the impulses are received.

Disc Ratio Tester.

This instrument, made by Messrs. Siemens Bros. and

shown in Fig. 78, can be used only for the measurement of the impulse ratio of dials when removed from working circuits. Thus its application is limited as compared with the previous ratio testers, but it has the advantage of extreme simplicity. The dial to be tested is mounted centrally on the underside of the vertical cross bar, which is hinged for this purpose, and, when the cross bar is in the normal position as shown, the dial faces downwards, leaving only the mechanism visible. The finger hole *O* (corresponding to 10 impulses) engages with a pin on the large disc, which is pivoted at the centre, and, therefore, the dial can be operated by rotating the disc. The make and break of the impulsing contacts of the dial is indicated by a small lamp wired to springs which engage with the dial terminals, and it is therefore possible to check that the makes and breaks occur at the correct points when the disc, together with the dial finger plate, is rotated; the disc is calibrated in relation to a pointer at the top of the cross bar for this purpose. It is necessary to restrain the dial so that it sends out impulses at a very low frequency while the measurements are being made, and, therefore, slight errors may occur owing to the absence of inertia effects which are present in the dial mechanism when running at normal frequencies. The disc tester is particularly useful, however, for detecting variations of ratio among individual impulses.

Clockwork Impulse Frequency Tester.

This instrument, which is made by the Automatic Telephone Manufacturing Co., Ltd, consists of a clockwork escapement mechanism and an impulse counting switch, the whole being enclosed in a case only 8 in. \times 4 in. \times 3 in. (Fig. 79). To re-set the instrument ready for a test, the handle shown is rotated anti-clockwise through 180° , thereby returning the pointers to the starting position at the left-hand side. As the impulses are received, they are counted by means of a magnet which actuates a ratchet wheel, and attached to this wheel is a pointer in the form of a ring, which travels over the upper scale to show the number of impulses received. At the beginning of the first impulse the clockwork mechanism is started, causing a

second pointer to move across the lower scale at a uniform speed, and when the "ring" pointer reaches the tenth position, the movement of the clockwork mechanism is stopped. Thus the distance travelled by the pointer over the lower scale during the transmission of the 10 impulses is a measure of the impulse frequency, and the lower scale is calibrated accordingly. It is essential, however, that only 10 impulses shall be transmitted, and, therefore, although

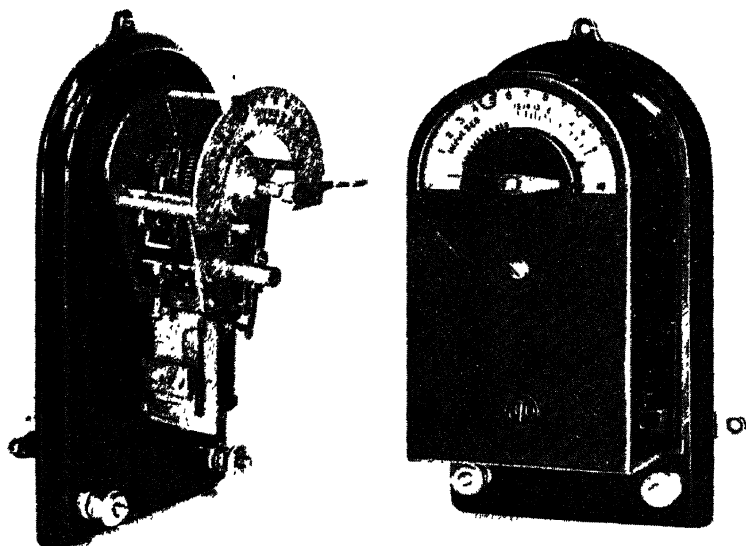


FIG. 79 CLOCKWORK IMPULSE FREQUENCY TESTER

this tester is suitable for measurement of dial frequency, it cannot be used for impulse machines which give continuous impulses unless special arrangements are made for the selection of 10 impulses only. If the number sent is other than 10, the clockwork mechanism is not arrested, and, therefore, the pointer moves over to the end of the scale, but the "ring" pointer on the upper scale shows the actual number of impulses received, in order that the observer may see what fault has occurred.

Pendulum Frequency Tester.

The essential part of this tester, which is manufactured by Messrs. Siemens Bros., is a pendulum which has a fixed time of swing (Fig. 80). It is released from its resting position at the commencement of the train of impulses,

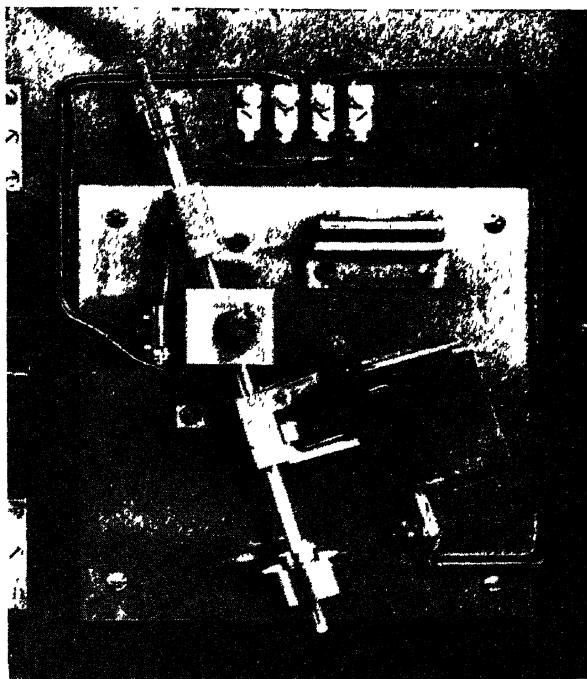


FIG. 80. PENDULUM FOR IMPULSE FREQUENCY TESTING

and the impulse frequency is determined by the number of impulses received during the period of swing. This is the reverse of the action of the A.T.M. clockwork tester described previously, which measured the time taken for a fixed number of impulses.

The counting of the impulses is effected by means of an assembly of relays, uniselectors, keys, lamps, etc., in a circuit which is shown in Fig. 81. It will be noted on

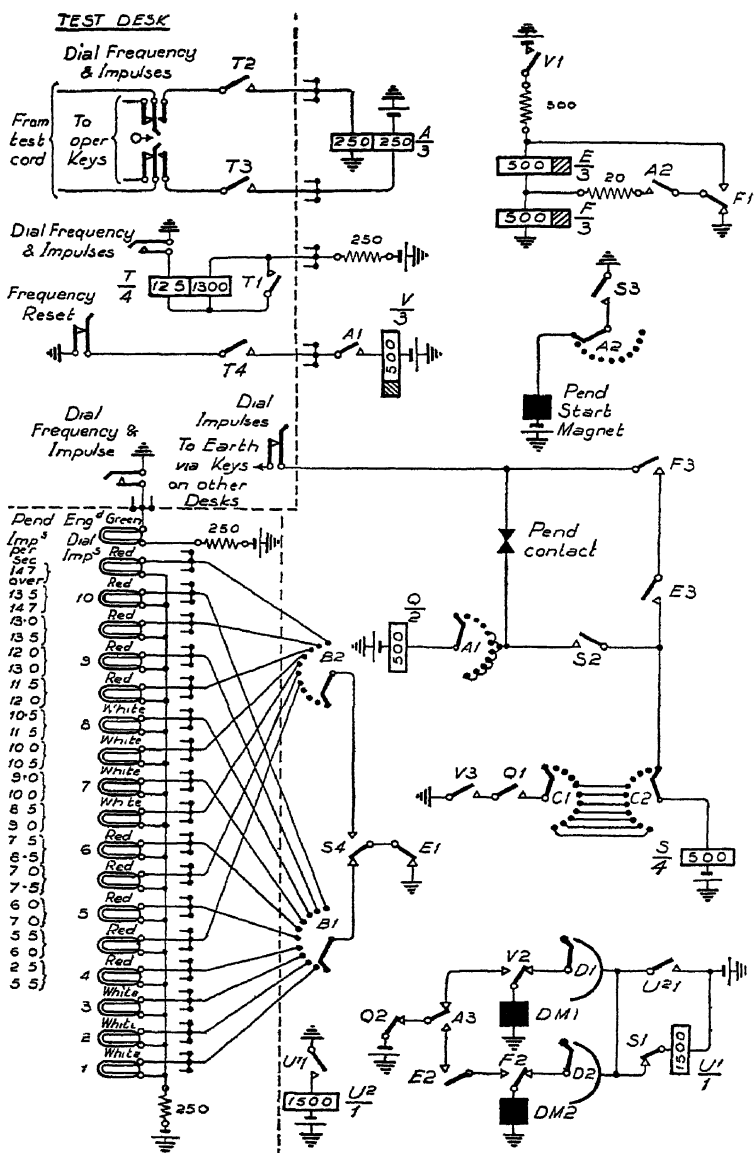


FIG. 81. PENDULUM IMPULSE FREQUENCY TESTER

that circuit diagram that the controls are multiplied to a number of test desks, but that the main portion of the tester, together with the pendulum, is a single unit common to the exchange. A detailed account of the circuit operation is unnecessary, but the general method of operation is described briefly below.

To make frequency tests the key "Dial Frequency and Impulses" is thrown. This connects the *A* relay to the test cord which contains the impulsing circuit to be tested. It also lights the "Pendulum Engaged" lamp at all other test desks. On receipt of the first break impulse, relays *F* and *S* operate and the "pendulum start magnet" releases the trigger which was previously restraining the pendulum. As soon as the pendulum moves, it opens the "Pendulum Contacts." During the subsequent impulses the operation of contact *A3* steps the two uniselector magnets *DM1* and *DM2* alternately, so that every make and every break impulse is recorded separately until, finally, the pendulum completes its swing, re-closing the "Pendulum Contacts" and operating relay *Q*. Relay *S* has now a new function in determining, by the positions of the *C* arcs of the two uniselectors, whether a break impulse or a make impulse was the last to be received. According to the position of contact *S4*, therefore, one or other of the *B* arcs of the uniselectors is selected, and the corresponding wiper determines which of the frequency indicating lamps is to be illuminated. These lamps are calibrated direct in "impulses per second" from 14.7 down to 2.5.

Other facilities provided are: (a) resetting of the uniselectors by means of a reset key releasing relay *V*; (b) disconnection of the indicating lamps until the end of the train of impulses by means of relay *E*; and (c) counting of the number of impulses (from a dial, for example) by throwing the "Dial Impulses" key, thereby disconnecting the "Pendulum Contacts." It will be noted that on the circuit illustrated, the lamps which indicate impulse frequencies outside the range of 8.5 to 11.5 i.p.s. are red, to indicate departure from a specified range.

APPENDIX I

TIME LAGS OF A.T.M. TYPE RELAYS AND MAGNETS IN TYPICAL AUTOMATIC TELEPHONE CIRCUITS
(The time lags quoted represent a fair average, and are those obtained with working currents)

Code	Title	Resistance (ohms)	No. of Spring Assemblies	Type of Relay	Operate Current	Operate Lag	Release Lag
L	LINE CIRCUIT RELAYS						
K	Calling line . . .	630	2	Heel slug, $1\frac{1}{16}$ in. . .	(mA.) 24	(mS.) 50	(mS.) 100
	Unselector wiper cut-in	1300	4	Fast . . .	26	40	10
A	FINAL SELECTOR RELAYS						
	Impulsing . . .	$\left\{ \begin{array}{l} 200 \\ + 200 \end{array} \right\}$	1	Impulsing, fast . . .	14.5	10	8
B	Guard . . .	$\left\{ \begin{array}{l} 700 \\ + 1000 \end{array} \right\}$	3	Heel slug, $1\frac{1}{2}$ in. . .	12	12	350
C	Impulse control . . .	$\left\{ \begin{array}{l} 4 \\ 200 \end{array} \right\}$	1	Heel slug, $1\frac{1}{16}$ in. . .	116	15	150
D	Forward supervisory . . .	$\left\{ \begin{array}{l} + 200 \end{array} \right\}$	3	Fast . . .	20	15	8
E	Rotary control . . .	$\left\{ \begin{array}{l} 350 \\ 200 \end{array} \right\}$	3	Heel slug, $1\frac{1}{16}$ in. . .	18	10	250
F	Ranging trip . . .	$\left\{ \begin{array}{l} + 1300 \end{array} \right\}$	4	Armature slug, 1 in . . .	$\left\{ \begin{array}{l} 26x \\ 20 \end{array} \right\}$	100	80*
G	Test . . .	$\left\{ \begin{array}{l} 2000 \\ 125 \end{array} \right\}$	4	Standard fast . . .	10	40	6
H	Wiper cut-in . . .	$\left\{ \begin{array}{l} 1200 \end{array} \right\}$	7	Armature slug, $1\frac{1}{16}$ in. . .	$\left\{ \begin{array}{l} 27x \\ 32 \end{array} \right\}$	100	30

"x" indicates operate currents measured on low resistance winding for x operation only, the figure below being that on the other winding for full operation.

* Releasing lag measured at the x contact, as this is the more important. In all other cases the lags are measured at the contact nearest the armature.

TIME LAGS OF A.T.M. TYPE RELAYS AND MAGNETS (contd.)

Code	Title	Resistance (ohms)	No of Spring Assemblies	Type of Relay	Operate Current (mA)	Operate Lag (mS.)	Release Lag (mS)
FIRST CODE SELECTOR RELAYS							
A	Impulsing . . .	$\left\{ \begin{array}{l} 200 \\ + 200 \end{array} \right\}$	1	Impulsing, fast . .	20	12	6
B	Guard . . .	800	5	Heel slug, $1\frac{1}{2}$ in. .	15	12	350
BA	Additional guard .	1000	4	Armature slug, $1\frac{1}{2}$ in. .	20	60	200
C	Impulse control . .	800	6	Heel slug, $1\frac{1}{2}$ in. .	15	10	200
D	Forward supervisory .	$\left\{ \begin{array}{l} 350 \\ + 1300 \end{array} \right\}$	1	Shunt field . . .	6	10	70
G	Test . . .	$\left\{ \begin{array}{l} 210 \\ + 1300 \end{array} \right\}$	3	Fast . . .	100	8	4
H	Wiper cut-in . . .	N.I.	4	Standard fast	27	50	3
I	High impedance . .	1300	1	Nickel-iron, fast . .	11	10	5
K	Unselector wiper cut-in	400	8	Fast . . .	27	45	4
L	Calling line . . .	$\left\{ \begin{array}{l} 200 \\ + 200 \end{array} \right\}$	2	Impulse repeating . .	15	10	9
M	Forced release . .	$\left\{ \begin{array}{l} 2 \\ + 1000 \end{array} \right\}$	9	Standard fast . . .	$\left\{ \begin{array}{l} 412x \\ 35 \end{array} \right\}$	50	2
MD	Meter delay . . .	800	3	Heel slug, $1\frac{1}{2}$ in. .	16	10	2

"x" indicates operate currents measured on low resistance winding for *x* operation only, the figure below being that on the other winding for full operation.

TIME LAGS OF A T.M. TYPE RELAYS AND MAGNETS (contd.)

Code	Title	Resis. (ohms)	Remarks	Operate Lag	Release Lag
	UNISELECTOR MAGNET			(mS.)	(mS.)
DM	Driving magnet . . .	75	Time lags of impulses other than the first . . .	12	4
V	SELECTOR MAGNETS, ETC				
	Vertical magnet . . .	46	Time lags of impulses other than the first . . .	25	3
R	Rotary magnet . . .	46	Time lags of impulses other than the first . . .	20	5
Z	Release magnet . . .	83	Normal operation . . .	20	—
N	Off-normal springs . . .	—	Drop of shaft from tenth level . . .	—	40
NR	Rotary off-normal . . .	—	Rotation of shaft from tenth contact . . .	—	180

APPENDIX II

BRITISH STANDARD TERMS* AND DEFINITIONS RELATING TO THE TEXT

<i>Term</i>	<i>Definition</i>
Automatic telephone system (machine-switching telephone system) . . .	A telephone system in which the calling subscriber is enabled, without the aid of an operator, to complete a call through remotely controlled selectors.
Bank . . .	In automatic telephony: An assemblage of fixed contacts with which a wiper engages. Banks are usually multiplied
Battery dialling . . .	A system of dialling which employs break impulses in an earth return circuit having the impulsing battery at the dial end. (See also Loop Dialling)
Break impulse . . .	An impulse in which the change consists in interrupting a current.
Busy . . .	The condition of a line or a piece of apparatus when it is in use.
Call indicator working	A method whereby calls are passed to a manual exchange by dialling or equivalent means and the number required is displayed (by illuminated numbers or other means) in front of the operator at that manual exchange
Circuit . . .	A path in which an electric current may flow. Strictly speaking, a circuit is a complete circulating path, but the term is commonly employed to designate (a) a specific part of a complete path, and (b) an aggregation of paths
Coded call indicator working	Call indicator working is said to be "coded" when the step-by-step impulses are stored in, and subsequently discharged, in coded form, from a coder or its equivalent.
Dial . . .	A calling device arranged in the form of a rotatable disc.
Dialling . . .	In automatic telephony: The act of applying impulses to a circuit by means of a dial.

* Abstracted by permission of the British Engineering Standards Association from British Standard Specification No 204 (1930), "Terms and Definitions Used in Connection with Telegraphs and Telephones," official copies of which can be obtained from the Secretary of the Association, 28 Victoria Street, London, S.W.1.

<i>Term</i>	<i>Definition</i>
Director . . .	In a director system: The apparatus which receives and re-transmits the called subscriber's number, translating the code portion.
Director system . . .	A system of step-by-step automatic telephony, for use in large multi-exchange areas, which permits the trunking between exchanges in the area to be independent of the subscribers' numbers. In this system the subscriber's number includes letters or figures, which constitute a code for the exchange to which he is connected. This code, together with the remaining or numerical portion of the called subscriber's number, when dialed, is received and stored on apparatus termed the "director." The director translates the code into one or more trains of digits, which are made effective on code selectors to connect the caller to the required exchange. The numerical portion is not translated, but is transmitted to numerical selectors and final selectors.
Final selector . . .	A selector which establishes connection with the called subscriber's line.
Free	The disengaged condition of a circuit or apparatus.
Group selector . . .	A selector which selects a group of trunks by impulse action and subsequently selects an idle trunk in the group by hunting action.
Homing action . . .	In automatic telephony: The automatic operation of a uniselector in returning the wipers to their normal or "home" position when the uniselector has been released.
Hunting action. . .	The automatic operation of a selector or similar device in moving the wipers to their position of contact with a free outlet.
Impulse	A brief change of current produced in a circuit.
Impulse action . . .	The operation of a selector or other similar device in finding, by means of electrical impulses, a called line or group of links or lines. Impulse action is predetermined by a calling device
Impulse frequency	The number of impulses per second in a train or group of regularly recurring impulses.

<i>Term</i>	<i>Definition</i>
Impulse period .	. The time between the corresponding points of two successive impulses in a train or group of regularly recurring impulses.
Impulse ratio .	. The ratio of duration of an impulse to its impulse period
Incoming. .	. A term used to indicate the direction of traffic in a circuit. Thus, an incoming junction in an exchange is a junction carrying traffic to that exchange from another exchange. Similarly, in an automatic selector, the incoming path is the path by which traffic enters the selector.
Induction coil .	. In telephony: A transformer, usually with open magnetic circuit, suitable for developing voltages in its secondary coil which vary in polarity and strength with the rise and fall of a uni-directional current in the primary coil.
Jack . .	. In telephony: A device used generally for terminating the permanent wiring of a circuit, access to which is obtained by the insertion into the jack of a plug usually connected to a cord.
Level . .	. The rows of contacts of a selector bank which are selected by impulse or hunting action and along which the wipers are moved by impulse and/or hunting and/or finding action
Line . .	. The portion of a circuit that is external to the premises housing the apparatus.
Loop dialling .	. A system of dialling which makes use of break impulses in a loop circuit (See also Battery Dialling)
Make impulse .	. An impulse in which the change consists in starting a current.
Minimum pause .	. An interval introduced into the operation of a dial in order to give the selectors time to complete their hunting.
Negative wire .	. In automatic telephony: That wire of a circuit within an exchange which, when it is free, is connected to the negative pole of the battery.
Outgoing .	. A term used to indicate the direction of traffic in a circuit. Thus, an outgoing junction at an exchange is a junction carrying traffic from that exchange to another exchange. Similarly, in an automatic selector, the outgoing path is the path by which traffic leaves the selector.

<i>Term</i>	<i>Definition</i>
P-wire (Private)	. The wire which controls the guarding, holding, and normally the releasing of automatic switches.
Plug In telephony: a device usually connected to the conductors of a flexible cord and used to make connection with a jack.
Polarized relay	. A relay, the operation of which depends upon the direction as well as upon the magnitude of the current in the controlling circuit.
Positive wire In automatic telephony: That wire of a circuit within an exchange which, when it is free, is connected to the positive pole of the battery.
Private branch exchange (P B.X.)	. An exchange which is usually installed on the premises of a subscriber and which is connected to a public exchange.
Private exchange (P.X.)	. An exchange which serves a business or other organization and is not connected to a public exchange.
Relay An electrically operated device for opening and closing circuits.
Relay-set An assembly of relays, with or without associated condensers and/or coils mounted on a single plate and wired to a plug.
Repeater A device whereby currents received over one circuit are automatically repeated in another circuit or circuits, generally in an amplified form.
Repeating coil A special form of transformer used in telephone practice; ordinarily of unity ratio.
Routiner In automatic telephony: An equipment for testing apparatus or circuits automatically.
Selector An automatic switching device serving to select a particular contact or contacts by impulse and/or hunting and/or finding action.
Shunt field relay	. A relay with two windings and a closed magnetic circuit. Normally the direction of the current in the windings confines the magnetic flux to the closed magnetic circuit, but when the current is reversed in one winding the flux is caused to take a shunt path which effects the operation of the relay.

<i>Term</i>	<i>Definition</i>										
Standard cable	<p>An arbitrary uniform line in terms of which the attenuation of a line or network may be specified. The standard cable used in Great Britain for telephone measurements is characterized by the following constants—</p> <table> <tr> <td></td><td><i>Per loop mile</i></td></tr> <tr> <td>Resistance</td><td>. . 88 ohms</td></tr> <tr> <td>Capacity</td><td>. . 0.054 μF.</td></tr> <tr> <td>Inductance</td><td>. . 0.001 henry</td></tr> <tr> <td>Leakance</td><td>. . 1 μmho</td></tr> </table> <p>(This standard is now obsolescent.)</p>		<i>Per loop mile</i>	Resistance	. . 88 ohms	Capacity	. . 0.054 μ F.	Inductance	. . 0.001 henry	Leakance	. . 1 μ mho
	<i>Per loop mile</i>										
Resistance	. . 88 ohms										
Capacity	. . 0.054 μ F.										
Inductance	. . 0.001 henry										
Leakance	. . 1 μ mho										
Step-by-step automatic system	A system in which the individual selectors are actuated step-by-step by their own driving mechanism operated by impulses controlling electro-magnetic ratchet and pawl devices										
Subscriber's line	The line between a subscriber's station and an exchange.										
Test jack	A jack interposed in a circuit to facilitate routine testing and the localization of faults.										
Twin contacts	Duplicate contact points used on contact springs										
Two-step relay	A relay with two groups of contact springs, one group of which is operated by an initial small magnetic flux and both groups by a subsequent greater magnetic flux. The first group is said to be <i>x</i> operated. (See also <i>x</i> operation.)										
Unguarded interval	A period (usually a fractional part of a second) within which selection of an outlet can be made and connection follow, resulting in irregular operation through no fault in the circuit or selecting apparatus or agency, but because the occurrence of such period is inherent in the apparatus.										
Unselector	A selector having unidirectional motion.										
Wiper	That portion of the moving member of a selector or other similar device which engages with the contacts of a bank.										
<i>x</i> operation	The advance operation of a group of relay contacts. This may be effected as in a two-step relay (<i>q.v.</i>), by a double motion of the armature, and/or by the relative adjustment of the various groups of contacts.										

INDEX

"A" RELAY, 24, 112
 A.T.M. auto-type relay, 12
 Adjustment charts, A.T.M., 19,
 42, 97
 ———, Siemens, 11, 29, 97
 ———, current, 98
 ———, gauging, 28, 29, 41
 ———, impulsing relay, 117, 124,
 135
 ———, tension gauge, 39
 ——— tools, 47
 Air-gap, heel, 9, 16, 118, 87
 ———, hinge, 8, 13, 47, 55, 118
 (see also Residual)
 Alarm relays, delayed, 76, 83
 Alternating current relay, 71
 Ampere-turn adjustment, 88
 Annealing, 6, 16
 Arcing at contacts (see Spark
 quench)
 Armature (see sub-headings)
 — end slugs, 21, 55
 Artificial cable, 132
 Assembly, contact, 5, 8, 12, 14,
 45

 "B" RELAY, 24, 57, 111, 112,
 127, 136
 Back contacts (see Break con-
 tacts)
 — stop, armature, 3, 5, 14, 33
 Balanced windings, 59, 117, 138
 Ballistic galvanometer timing
 sets, 152
 Basic ampere-turns, 88
 Battery impulsing, 141
 Bell tinkling, 115
 Bias spring, 9
 BM (see Break-make)
 BMbB (see Make-before-break)
 Bounce, elimination of, 30, 32,
 89
 ———, examples of, 34, 118, 140,
 146
 Break contacts, 20, 27, 43

Break-make contacts, 29
 Buffers, 9, 31, 40, 69
 (see also Back-stop)

 "C" RELAY, 24, 112, 127, 136
 Cable, effect of, 132
 Carriage, armature, 8
 Centre-cheek coil, 15, 117
 Change-over contacts (see Break-
 make)
 — ——— time, 118
 Chattering (see Bounce)
 Chronometer, phonic, 150
 Circuit diagrams, 20
 Class of springs, 46
 Clearance, contact, 40, 46
 —, pip, 41, 44
 Clock-controlled relay, 77
 Clockwork impulse tester, 171
 Coherer effect, 36
 Coil construction, 11, 18
 —, heating of, 111
 — resistance limits, 97
 — tag lettering, 11, 18, 26
 Commutator for timing, 158
 Compensating resistance, 140
 Condenser bridge for timing, 160
 —, dial, 114, 122
 —, transmission, 133, 136
 Contact cleaner, 51
 Contacts, 5, 20, 33, 80
 (see also Sub-titles)
 Conventions for coils, 20, 59, 84
 — for contacts, 20
 Corrosion of windings, 10
 Coslettizing, 9
 Cost of relays, 2, 33, 70
 Current adjustment, 98
 Cut-off relay, 59, 68

 "D" RELAY, 24, 63, 133, 136
 Dashpot relay, 76
 Definitions, 20, 98, 181
 Delayed alarm relays, 76, 83
 Demagnetization, 99

- Design of relays, 86
 Diagrams, circuit, 20
 —, target, 125
 Dial, 112
 — condenser, 114, 122
 Dimensions of contacts, 34
 — of relays, 2, 5, 12, 14, 16, 70
 Dirty contacts (see Faults)
 Disc ratio tester, 170
 Dome contacts, 34
 Double connection, 106
 — contact springs, 29
 — dog, 73
 — make contacts, 30
 Duckbill pliers, 50
- “E” RELAY, 24
 Earth potential difference, 142
 Eddy currents, 52, 111
 Electrostatic relay, 1
 — voltmeter for timing, 153
 Ericsson relay, 13
 Examples of calculations, 89, 92
 Extension telephone, 133
- “F” RELAY, 24, 58
 Fast relays, 52, 60, 70
 Faults, contact, 2, 5, 8, 30, 33, 40, 51
 —, selector, 127, 136
 —, spring, 50
 Figure of merit (see Operate current)
 Final selector, 17, 20, 58, 133, 136
 Finish, protective, 9, 16, 87
 First impulse, distortion of, 121
 Flat-type relay, 70
 Flux (see Magnetic)
 Follow of springs, 29, 39, 84
 Frequency, impulse, 116, 120, 124, 171
 Front contact (see Make contact)
 — stop, 31, 129
- “G” RELAY, 241
 G.E.C. relay, 6
 Gauging adjustment, 41
 Gravity control, 3, 71, 77, 82
 Guide resistance, 101
- “H” RELAY, 24
 Heating of relays, 99, 111, 141
 Heavy currents, 33, 80
 Heel air-gaps, 9, 16, 87, 118
 — piece, 15 (see also Yoke)
 — slug, 21, 53
 High impedance relay, 60, 136
 Hinge air-gap, 6, 13, 47, 55, 118
 Hold current, 99
 Hunting speed, 35, 75, 76
- “I” RELAY, 60, 136
 Impedance of relays, impulsing, 59, 117, 138
 —, nickel-iron, 60, 136
 —, sluggish, 53, 103
 Impulse ratio (see Ratio)
 — repetition, 117, 136
 — speed (see Frequency)
 Impulses, generation of, 67, 112, 115, 127, 158
 Impulsing, battery, 141
 —, loop, 112
 — relays, adjustment, 46, 117, 124, 135
 —, requirements of, 115, 135
 —, springs, 32, 34, 118
 —, reverted, 143
 Induced voltage on lines, 60, 115
 Inductive energy, 36
 Inertia of armatures, 53, 72
 — effect (pulse operation), 105
 Insulating wedge for contacts, 51
 Insulation of lines, 115, 116, 120, 132, 142
 — of relays from mounting, 10, 16
 — of springs, 9, 14
 — of windings, 18
 Interference, magnetic, 3, 111
 Interlocking relays, 68
 Isenthal relay, 81
 Isthmus armatures, 119
- JUNCTIONS, 116, 136, 141
- “K” RELAY, 59, 68, 106
 Knife-edge armatures, 4, 6

- “L” RELAY, 68, 141
- Lag (see Time)
- Leak on lines, effect of, 120, 132, 142
 - — —, limits of, 116
- Leakage flux, 3, 53, 56, 111, 90
- Lettering of coil tags, 11, 19, 26, 98
 - of relays, 25, 98
- Leverage of armatures, A.T.M., 14, 41, 45, 47, 55, 110
 - — —, Siemens, 9, 47
- Life of contacts, 34, 81
- Lifting pin (Siemens), 8, 41
- Line and cut-off relay (A.T.M.), 68
- Locking coil, 28, 58
- Loop impulsing circuit, 112, 136
 - resistance, compensation, 140
 - — —, effect of, 119, 132, 142
 - — —, limits of, 116, 141
- MbB (see Make-before-Break)
- Magnetic circuit, 1, 6, 13, 52, 86, 111
 - interference, 3, 111 (see also Air-gap)
- Magnet, selector, 73, 112
 - — —, performance of, 125
 - — —, spark quenching, 34, 38
 - — —, unselector, 76
- Maintenance (see Adjustments; Faults)
- Make contacts, 20, 27
- Make-before-break contact, 21, 29, 45, 90
 - — —, bounce of, 33
 - — —, impulsing, 118
- Manual type relays, 2
- Marginal relay, 65
- Measurement of time lags, 144
- Mercury contacts, 81
- Metal rectifiers, use of, 72
- Metroscope, 162
- Millammeter ratio tester, 167
- Millisecond meter, 154
- Motor-start relay, 80
- Mounting of relays, 10, 16, 98, 111
- Moving coil relay, 83
 - spring, 8, 14, 20
- Multi-contact relay, 5
- “N” SPRINGS, 75, 114
- “NR” springs, 75
- Neon relay, 1
- Nickel-iron relay, 60, 136
- Nickel plating, 9, 16, 87 (see also Air-gaps, Wear)
 - silver springs, 5, 8, 13 (see also Pile, spring)
- Non-inductive winding, 18
- Non-operate current, 43, 58, 100
- Normal post springs, 76
- Notched springs, 33
- Numbering of contacts, 27, 97
- OFF-NORMAL contacts, 75, 112, 114
- Open period, 106
- Opening, contact, 40, 46
- Operate current, 40, 88, 97, 100
 - — —, marginal, 65, 135
- Operating time, 52, 55, 61, 77, 102, 117, 177
 - — —, pulse, 105, 128, 159
- Optical method of timing relays, 162
- Oscillations, condenser (see Surges)
- Oscillograms, 123, 139, 146
- Oscillograph, 144
- Overhead lines, 142
- P.G.S. CONTACTS, 33, 38
- Packet, spring (see Pile)
- Parallel, relays in, 57, 110
- Peel Conner relay, 6
- Pendulum impulse frequency tester, 173
 - relay, 66
- Percentage make (see Ratio)
- Perforated armatures, 119
- Performance of selectors, 112, 125
- Permanent magnets, 64, 72, 78
- Permeability, 60, 86, 111
- Phonic chronometer, 150

- Phosphor-bronze springs, 9, 12
 Pile, spring, 5, 8, 12, 14, 45, 89
 ———, buffers in, 9, 31, 40, 69
 ———, tools for, 47
 Pin type armature, 8, 13, 118
 Pip clearance, 41, 44
 ——— and plate contacts, 34
 Plating, protective, 9, 16, 87
 Platinum contacts, 33, 38
 Platit contacts, 33
 Pliers for spring adjustment, 49
 Polarized relays, 63, 78
 Polarity of contacts, 34
 Pole piece, 5, 9, 63
 ———, wear of, 55, 110, 135
 Potential, earth difference, 142
 ——— induced on line, 60, 115
 Power Equipment Co.'s relay, 80
 Pressure, contact, 3, 39
 ———, effect of buffers, 31
 ———, of gauging, 43
 ——— on bounce, 32, 89
 ——— on wear, 35
 ———, minimum, 40, 89
 ———, on break contacts, 43
 ———, on MbB contacts, 31, 33
 ———, on magnet contacts, 35
 ———, on twin contacts, 31
 ———, spring, effect of heating, 111
 ——— on operate current, 40, 88
 ———, on slow relays, 55
 Private wire, 106
 Protective finish, 9, 16, 87
 Pulse-operated relay, 83
 Pulse-operating time, 105, 128, 159
 Push-button control, 83
 QUENCH, spark, 36
 "R" MAGNET (see Selector)
 R.A.T. Co.'s relay, 11, 83
 Ratchet relay, 77
 Ratio of armatures (see Leverage)
 ———, impulse, distortion, 121
 ———, limits of, 116
 ———, measurement of, 167
 Readjust current, 100
 Recording timing instruments, 144, 149
 Relay (see Sub-headings)
 Release current, 10, 55, 90, 99, 109, 110 (see also Residual)
 ——— magnet, 38, 73, 114
 Releasing time, 53, 57, 61, 108, 117, 128, 177
 Repeating coil bridge, 133
 Repetition, impulse, 136
 Representation of relays, 20, 59, 84
 Requirements of relays, 2
 Residual (air-gap), gauging of, 46
 ———, need for, 9
 ——— on fast relays, 10, 11, 15, 69
 ——— on impulsing relays, 118, 135
 ——— on slow relays, 55
 ——— magnetism, 10, 118
 ——— screw, wear by, 55, 110, 135
 Resistance, line (see Loop; Leak)
 ——— of coils, 97
 ——— of contacts, 35
 Retards, 60
 Reverted impulsing, 143
 Rigid contacts, 3, 79
 ———, bounce of, 32
 ———, tension gauging of, 39
 Ringing trip relay, 57
 Riveting of contacts, 34
 Rocker armatures on relays, 5, 11, 13, 73
 Rotary magnet (see Selector)
 ——— off-normal springs, 75
 Routiner, 25, 165
 Rub of contacts, 41
 S. T. & C. RELAY, 13, 71, 72
 Sandwiched winding, 11
 Saturate current, 88, 98, 109

- Saturation, impulsing effects, 119, 121
 — — — — — with isthmus armature, 119
 Schematic circuit diagrams, 27, 59, 62, 113, 137, 157, 174
 Selector magnets, 38, 73
 — operation, 74, 112
 — performance, 125
 — relay mounting, 10, 16, 98, 111
 — spark quench, 34, 38
 Self-drive, 35, 74
 — — — — — protective windings, 99, 111
 Semi-detached contact diagram, 27, 59, 62, 113, 137, 157, 174
 Sensitivity (see Operate current)
 Shape of contacts, 34
 Shell type relay, 2
 Sherardizing, 16
 Short circuited winding, 57, 104, 110
 Shunted winding as spark quench, 38
 — — — — — effect on timing, 57, 105, 110, 142
 Shunt-field relay, 46, 63, 136
 Shutter for timing relays, 162
 Side-mounting of relays, 8, 16
 Siemens relay, 6, 81
 Silver contacts, 3, 33
 Sleeves, copper, 21, 57, 58
 — — — — — nickel-iron, 60
 Slow operating relay, slugged, 21, 55, 58, 102
 — — — — — alarm, 76, 83
 — — — — — releasing relays, 21, 53, 57, 108, 127
 Slug, armature end, 21, 55, 58
 — — — — — effect on impedance, 53
 — — — — — heel, 21, 53
 Solenoid relay, 76, 80
 Space, relay winding, 4, 71, 92
 — — — — — requirements of relays, 2, 70
 Spark quench, 36, 115, 142
 Speech current, coherer effect, 36
 — — — — — impedance to, 60, 136
 — — — — — relay, 72
 Speed, impulse (see Frequency)
 Spools (see Coil)
 Spring capacity, 5, 8, 12, 18
 — — — — — load (see Pressure)
 Standard "B" telegraph relay, 78
 — — — — — cable, 132
 Start relay, motor, 80
 Stone transmission bridge, 133
 Stop pin (see Residual)
 Stray flux, 3, 111
 Stroke (see Travel)
 Stroking of springs, 50
 Subscriber's telephone circuit, 58, 68, 114, 133
 Sub-station relay, 81
 Surges, dial condenser, 122
 — — — — — ringing current, 58
 — — — — — transmission bridge, 136
 TAG lettering of coils, 11, 19, 26, 98
 Target diagram, 125
 Telegraph relay, 78
 Telephone instrument circuit, 58, 68, 114, 133
 Tension gauge, 39
 — — — — — spring (see Pressure)
 Terms, B.E.S.A., 181
 Test current, 58, 100
 — — — — — points, 101
 Tester for frequency, 171
 — — — — — impulse ratio, 167
 — — — — — relay timing, 144
 Thermostat relay, 12, 83
 Thickness gauge, broad bladed, 41
 — — — — — narrow bladed, 47
 — — — — — wire type, 46
 — — — — — of springs, A.T.M. type, 32, 46, 90
 — — — — — Siemens type, 40, 90
 Time check relay, 77
 — — — — — graph, 106
 — — — — — lags, typical, 177
 — — — — — operating, 52, 55, 61, 77, 102, 117
 — — — — — releasing, 53, 57, 61, 108, 117, 128
 Tolerances on current adjustments, 65, 100, 135

- Tolerances on gauging, 47, 135
 — on resistance, 97
 — on time lags, 105, 110
 Tones, generation of, 68
 Tools, adjustment, 47
 Torpedo relay, 2
 Touch-operate current, 100
 Transmission bridge, 133, 136
 Travel, armature, 3, 30, 40, 71,
 118 (see also Back
 stop; Leverage)
 — time (transit time), 103,
 108, 118, 147
 Travelling spring, 8, 14, 20
 Tungsten contacts, 33, 38, 81
 Twin contacts, 30
 Two-step relay, 28, 46, 62

 UNDERGROUND cable, 132
 Unguarded interval, 106
 Uniselector, construction, 76
 — method of timing relays,
 165
 — spark quench, 34, 38
 —, subscriber's circuit, 58, 68
 —, unguarded intervals, 106

 "V" MAGNET (see Selector mag-
 net)
 Vacuum tube relay, 1
 Valve relay, thermionic, 1
 Variable interrupter timing
 method, 158

 Vertical magnet (see Selector)
 Vibration of relays, 110
 — of springs (see Bounce)
 Voice-frequency relay, 72
 Voltage, battery, effect of, 134
 — —, limits of, 116

 WAVE form, impulsing, 123, 139
 (see also Surges)
 Wear of armature pivot, 42
 — of contacts, 35, 37
 — by residual screw, 55, 110,
 135
 Wedge for insulating contacts,
 51
 Welding of contacts (faults), 37,
 115, 142
 — — (mounting), 34
 Western Electric auto relay, 13
 Weston Elec Inst Co's relay, 83
 Winding (see Coil)
 — data, 92
 — space, 4, 71, 91
 Wipe of contacts, 41
 Wire-type thickness gauge, 46
 Wiring diagram, 27

 "X" CONTACT, 27, 58, 82, 108

 "Y" CONTACT, 28
 Yoke, 4, 6, 11, 14

 "Z" MAGNET, 38, 73, 114

An Abridged List of TECHNICAL BOOKS

PUBLISHED BY

Sir Isaac Pitman & Sons, Ltd.

Parker Street, Kingsway, London, W.C.2

The prices given apply only to Great Britain

A complete Catalogue giving full details of the following books will be sent post free on application

CONTENTS

	PAGE		PAGE
AERONAUTICS	9	MATHEMATICS AND CALCULATIONS FOR ENGINEERS	15-17
ART AND CRAFT WORK . .	2	MECHANICAL ENGINEERING	8, 9
ARTISTIC CRAFT SERIES . .	2	METALLURGY AND METAL WORK	5
ASTRONOMY	11	MINERALOGY AND MINING . .	6
CIVIL ENGINEERING, BUILDING, ETC	7, 8	MISCELLANEOUS TECHNICAL BOOKS	17
COMMON COMMODITIES AND INDUSTRIES SERIES	20-23	MOTOR ENGINEERING . .	10
DRAUGHTSMANSHIP	4	OPTICS AND PHOTOGRAPHY . .	11
ELECTRICAL ENGINEERING, ETC	11-14	PHYSICS, CHEMISTRY, ETC . .	4, 5
ILLUMINATING ENGINEERING	11	TECHNICAL PRIMERS . .	18-20
MARINE ENGINEERING . .	9	TELEGRAPHY, TELEPHONY, AND WIRELESS	15
		TEXTILE MANUFACTURE, ETC.	3

ALL PRICES ARE NET

THE ARTISTIC CRAFT SERIES

s. d.

BOOKBINDING AND THE CARE OF BOOKS. By Douglas Cockerell. Fourth Edition	7	6
DRESS DESIGN. By Talbot Hughes	12	6
EMBROIDERY AND TAPESTRY WEAVING By Mrs A H Christie Fourth Edition	10	6
HAND-LOOM WEAVING By Luther Hooper	10	6
HERALDRY By Sir W H St John Hope, Litt D, D C L	12	6
SILVERWORK AND JEWELLERY By H Wilson Second Edition	8	6
STAINED GLASS WORK. By C W. Whall	10	6
WOOD-BLOCK PRINTING By F Morley Fletcher	8	6
WOODCARVING DESIGN AND WORKMANSHIP By George Jack	8	6
WRITING AND ILLUMINATING AND LETTERING By Edward Johnston. Sixteenth Edition	8	6

ART AND CRAFT WORK, ETC.

BLOCK-CUTTING AND PRINT-MAKING BY HAND By Margaret Dobson, A.R.E.	12	6
CABINET-MAKING, THE ART AND CRAFT OF By D. Denning	7	6
CELLULOSE LACQUERS By S Smith, O B E, Ph D	7	6
LACQUER WORK. By G Koizumi	15	0
LEATHER CRAFT. ARTISTIC By Herbert Turner	5	0
LEATHER WORK: STAMPED, MOULDED, CUT, CUIR-BOUILLI, SEWN, ETC. By Charles G Leland Third Edition	5	0
LETTERING AND DESIGN, EXAMPLES OF By J. Littlejohns, R B A	4	0
LETTERING, DECORATIVE WRITING AND ARRANGEMENT OF By Prof A. Erdmann and A A Braun Second Edition	10	6
LETTERING, PLAIN AND ORNAMENTAL By Edwin G Fooks	3	6
MANUAL INSTRUCTION: WOODWORK By S Barter	7	6
MANUSCRIPT AND INSCRIPTION LETTERS. By Edward Johnston	7	6
MANUSCRIPT WRITING AND LETTERING By an Educational Expert.	6	0
METAL WORK. By Charles G Leland Second Edition	5	0
NEEDLEWORK IN RELIGION. By Mrs Antrobus and Miss Precce	21	0
ORNAMENTAL HOMECRAFTS By Idaha B. Littlejohns	10	6
PLYWOOD AND GLUE, MANUFACTURE AND USE OF. By B C Boulton, B Sc	7	6
POTTERY, HANDCRAFT. By H and D Wren	12	6
STAINED GLASS, THE ART AND CRAFT OF. By E W. Twining	42	0
STENCIL-CRAFT By Henry Cadness, F S A M.	10	6
WEAVING FOR BEGINNERS. By Luther Hooper	5	0
WEAVING WITH SMALL APPLIANCES— THE WEAVING BOARD. By Luther Hooper	7	6
TABLE LOOM WEAVING By Luther Hooper	7	6
TABLET WEAVING. By Luther Hooper	7	6
WOOD CARVING. By Charles G. Leland Fifth Edition	7	6
WOODCARVING, HANDICRAFT OF. By James Jackson	4	0

TEXTILE MANUFACTURE, ETC.

	s	d.
ARTIFICIAL SILK AND ITS MANUFACTURE By Joseph Foltzer. Translated into English by T Woodhouse. Fourth Edition	21	0
ARTIFICIAL SILK By Dr V Hottenroth Translated from the German by Dr E Fyleman, B Sc	30	0
ARTIFICIAL SILK By Dr O Faust	10	6
ARTIFICIAL SILK OR RAYON, ITS MANUFACTURE AND USES By T Woodhouse, F T I Second Edition	7	6
ARTIFICIAL SILK OR RAYON, PREPARATION AND WEAVING, THE By T. Woodhouse, F T I	10	8
BLEACHING, DYEING, PRINTING, AND FINISHING FOR THE MAN- CHESTER TRADE By J W McMyn, F C S, and J W Bardsley	6	0
COLOUR IN WOVEN DESIGN By Robert Beaumont, M Sc, M I Mech E Second Edition, Revised and Enlarged	21	0
COTTON SPINNER'S POCKET BOOK, THE By James F Innes	3	6
COTTON SPINNING COURSE, A FIRST YEAR By H A J Duncan, A T I	5	0
COTTON WORLD, THE Compiled and Edited by J A. Todd, M A, B L	5	0
DRESS, BLOUSE, AND COSTUME CLOTHS DESIGN AND FABRIC MANUFACTURE By Roberts Beaumont, M Sc, M I Mech E and Walter G Hill	42	0
FLAX AND JUTE, SPINNING, WEAVING, AND FINISHING OF By T Woodhouse, F T I	10	6
FLAX CULTURE AND PREPARATION By F Bradbury Second Edition	10	6
FURS AND FURRIERY By Cecil J Rosenberg	30	0
HOSIERY MANUFACTURE By W Davis, M A	7	6
MEN'S CLOTHING, ORGANIZATION, MANAGEMENT, AND TECHNOLOGY IN THE MANUFACTURE OF By M E. Popkin	25	0
PATTERN CONSTRUCTION, THE SCIENCE OF For Garment Makers By B W Poole.	45	0
TEXTILE CALCULATIONS By J H Whitwam, B Sc (Lond)	25	0
TEXTILE EDUCATOR, PITMAN'S Edited by L J Mills, <i>Fellow of the Textile Institute</i> In three volumes	63	0
TEXTILES, INTRODUCTION TO By A E Lewis, A M C T.	3	6
TOWELS AND TOWELLING, THE DESIGN AND MANUFACTURE OF. By T Woodhouse, F T I, and A Brand, A T I	12	6
UNION TEXTILE FABRICATION By Roberts Beaumont, M Sc, M I Mech E	21	0
WEAVING AND MANUFACTURING, HANDBOOK OF. By H. Greenwood, A T I	5	0
WOOLLEN YARN PRODUCTION By T. Lawson	3	6
WOOL SUBSTITUTES By Roberts Beaumont.	10	6
YARNS AND FABRICS, THE TESTING OF By H. P. Curtis	5	0

Physics, Chemistry, etc.—contd. *s d*

PHYSICS, EXPERIMENTAL By A Cowling With Arithmetical Answers to the Problems	1	9
PHYSICS, TEST PAPERS IN By P. J Lancelot-Smith, M.A.	2	0
Points Essential to Answers, 4s In one book	5	6
VOLUMETRIC ANALYSIS By J B Coppock, B Sc (Lond), F I C , F C S. Second Edition	3	6
VOLUMETRIC WORK, A COURSE OF By E. Clark, B.Sc.	4	6

METALLURGY AND METAL WORK

BALL AND ROLLER BEARINGS, HANDBOOK OF By A. W. Macaulay, A M I Mech E	7	6
ENGINEERING MATERIALS, Volume I FERROUS. By A W Judge, Wh Sc , A R C S	30	0
ENGINEERING MATERIALS, Volume II AIRCRAFT AND AUTOMOBILE MATERIALS—NON-FERROUS AND ORGANIC By A W Judge, Wh.Sc , A R C S	25	0
ENGINEERING MATERIALS, Volume III. THEORY AND TESTING OF MATERIALS FERROUS By A W Judge, Wh Sc , A.R.C.S	21	0
ENGINEERING WORKSHOP EXERCISES By Ernest Pull, A M I Mech E , M I Mar E Second Edition, Revised	3	6
FILES AND FILING By Ch. Fremont Translated into English under the supervision of George Taylor	21	0
FITTING, THE PRINCIPLES OF By J Horner, A M I M E Fifth Edition, Revised and Enlarged	7	6
IRONFOUNDING, PRACTICAL. By J Horner, A M I M E Fourth Edition	10	0
IRON ROLLS, THE MANUFACTURE OF CHILLED By A Allison	8	6
JOINT WIPING AND LEAD WORK By William Hutton Third Edition	5	0
METAL TURNING By J Horner, A M I M E Fourth Edition, Revised and Enlarged	6	0
METAL WORK, PRACTICAL SHEET AND PLATE By E A Atkins, A M I M E Third Edition, Revised and Enlarged	7	6
METALLURGY OF CAST IRON By J. E. Hurst	15	0
PATTERN MAKING THE PRINCIPLES OF By J Horner, A M I M E Fifth Edition	4	0
PIPE AND TUBE BENDING AND JOINTING By S P. Marks, M S I A	6	0
PYROMETERS By E Griffiths, D Sc	7	6
STEEL WORKS ANALYSIS By J O Arnold, F R S , and F. Ibbotson Fourth Edition, thoroughly revised	12	6
TURRET LATHE TOOLS, HOW TO LAY OUT Second Edition	6	0
WELDING, ELECTRIC By L B. Wilson	5	0
WELDING, ELECTRIC ARC AND OXY-ACETYLENE. By E. A. Atkins, A M I M E	7	6
WORKSHOP GAUGES AND MEASURING APPLIANCES. By L. Burn, A M I Mech E , A M I E.E.	5	0

MINERALOGY AND MINING.		s. d.
BLASTING WITH HIGH EXPLOSIVES. By W. Gerard Boulton .	5	0
COAL CARBONIZATION. By John Roberts, D.I.C., M.I.Min.E., F.G.S.	25	0
COAL MINING, DEFINITIONS AND FORMULAE FOR STUDENTS. By M. D. Williams, F.G.S.	-	6
COLLIERY ELECTRICAL ENGINEERING By G. M. Harvey. Second Edition	15	0
COMPRESSED AIR POWER By A. W. Daw and Z. W. Daw .	21	0
ELECTRICAL ENGINEERING FOR MINING STUDENTS. By G. M. Harvey, M.Sc., B.Eng., A.M.I.E.E.	5	0
ELECTRICITY APPLIED TO MINING By H. Cotton, M.B.E., M.Sc., A.M.I.E.E.	35	0
ELECTRIC MINING MACHINERY By Sydney F. Walker, M.I.E.E. M.I.M.E., A.M.I.C.E., A.Amer.I.E.E.	15	0
LOW TEMPERATURE DISTILLATION By S. North and J. B. Garbe	15	0
MINERALOGY. By F. H. Hatch, Ph.D., F.G.S., M.I.C.E., M.I.M.M. Fifth Edition, Revised	6	0
MINING CERTIFICATE SERIES, PITMAN'S Edited by John Roberts, D.I.C., M.I.Min.E., F.G.S., Editor of <i>The Mining Educator</i> —		
MINING LAW AND MINE MANAGEMENT By Alexander Watson, A.R.S.M.	8	6
MINE VENTILATION AND LIGHTING. By C. D. Mottram, B.Sc.	8	6
COLLIERY EXPLOSIONS AND RECOVERY WORK By J. W. Whitaker, Ph.D (Eng.), B.Sc., F.I.C., M.I.Min.E.	8	6
ARITHMETIC AND SURVEYING. By R. M. Evans, B.Sc., F.G.S., M.I.Min.E.	8	6
MINING MACHINERY. By T. Bryson, A.R.T.C., M.I.Min.E.	12	6
WINNING AND WORKING. By Prof. Ira C. F. Stratham, B.Eng., F.G.S., M.I.Min.E.	21	0
MINING EDUCATOR, THE. Edited by J. Roberts, D.I.C., M.I.Min.E., F.G.S., In two vols.	63	0
MINING SCIENCE, A JUNIOR COURSE IN. By Henry G. Bishop.	2	6
MODERN PRACTICE OF COAL MINING SERIES. Edited by D. Burns, M.I.M.E., and G. L. Kerr, M.I.M.E.—		
II. EXPLOSIVES AND BLASTING—TRANSMISSION OF POWER	6	0
IV. DRILLS AND DRILLING—COAL CUTTING AND COAL- CUTTING MACHINERY	6	0
TIN MINING. By C. G. Moor, M.A.	8	6

CIVIL ENGINEERING, BUILDING, ETC. s d

AUDEL'S MASONS' AND BUILDERS' GUIDES	In four volumes		
	Each	7	6
1	BRICKWORK, BRICK-LAYING, BONDING, DESIGNS		
2	BRICK FOUNDATIONS, ARCHES, TILE SETTING, ESTIMATING		
2.	CONCRETE MIXING, PLACING FORMS, REINFORCED STUCCO		
4	PLASTERING, STONE MASONRY, STEEL CONSTRUCTION, BLUE PRINTS		
AUDEL'S PLUMBERS' AND STEAM FITTERS' GUIDES	Practical Handbooks in four volumes	Each	7 6
1	MATHEMATICS, PHYSICS, MATERIALS, TOOLS, LEADWORK		
2	WATER SUPPLY, DRAINAGE, ROUGH WORK, TESTS		
3	PIPE FITTING, HEATING, VENTILATION, GAS, STEAM		
4	SHEET METAL WORK, SMITHING, BRAZING, MOTORS		
"THE BUILDER" SERIES—			
ARCHITECTURAL HYGIENE, OR, SANITARY SCIENCE AS APPLIED TO BUILDINGS By Banister F. Fletcher, F R I B A, F S I, and H Phillips Fletcher, F R I B A., F S I, Fifth Edition, Revised			
		10	6
CARPENTRY AND JOINERY By Banister F Fletcher, F R I B A, F S I, etc., and H Phillips Fletcher, F R I B A, F S I, etc. Fifth Edition, Revised			
		10	6
QUANTITIES AND QUANTITY TAKING By W. E Davis Sixth Edition			
		6	0
BUILDING, DEFINITIONS AND FORMULAE FOR STUDENTS By T Corkhill, F.B.I.C.C., M.I.Struct E			
		—	6
BUILDING EDUCATOR, PITMAN'S Edited by R Greenhalgh, A I Struct E. In three volumes			
		63	0
FIELD MANUAL OF SURVEY METHODS AND OPERATIONS By A Lovat Higgins, B Sc, A R C S, A M I C E.			
		21	0
FIELD WORK FOR SCHOOLS By E H Harrison, B Sc., L.C.P., and C A Hunter			
		2	0
HYDRAULICS By E H. Lewitt, B.Sc (Lond), M.I.Ae E., A M I E Third Edition			
		10	6
JOINERY & CARPENTRY Edited by R Greenhalgh, A I.Struct E In six volumes			
		Each	6 0
PAINTING AND DECORATING Edited by C. H. Eaton, F.I.B.D In six volumes			
		Each	7 6
PLUMBING AND GASFITTING Edited by Percy Manser, R.P., A R S I In seven volumes			
		Each	6 0
REINFORCED CONCRETE, DETAIL DESIGN IN. By Ewart S Andrews, B Sc (Eng)			
		6	0
REINFORCED CONCRETE By W Noble Twelvetrees, M.I.M.E., A M I E E.			
		21	0
REINFORCED CONCRETE MEMBERS, SIMPLIFIED METHODS OF CALCULATING By W Noble Twelvetrees Second Edition, Revised and Enlarged			
		5	0

Civil Engineering, Building, etc.—contd. s d

SPECIFICATIONS FOR BUILDING WORKS By W L Evershed, F.S.I.	5	0
STRUCTURES, THE THEORY OF By H W Coultas, M Sc., A M I Struct E, A I Mech E	15	0
SURVEYING, TUTORIAL LAND AND MINE By Thomas Bryson	10	6
WATER MAINS, LAY-OUT OF SMALL By H H Hellins, M Inst C E.	7	6
WATERWORKS FOR URBAN AND RURAL DISTRICTS By H. C. Adams, M Inst.C E, M.I.C E., F.S.I	15	0

MECHANICAL ENGINEERING

AUDEL'S ENGINEERS' AND MECHANICS' GUIDES In eight volumes Vols 1-7 Each	7	6
Vol 8	15	0
CONDENSING PLANT By R. J Kaula, M I E E, and I V. Robinson, M I E E	30	0
DEFINITIONS AND FORMULAE FOR STUDENTS—APPLIED ME- CHANICS By E H Lewitt, B Sc, A M I Mech E	-	6
DEFINITIONS AND FORMULAE FOR STUDENTS—HEAT ENGINES. By A Rimmer, B Eng	-	6
DIESEL ENGINES MARINE, LOCOMOTIVE, AND STATIONARY By David Louis Jones, <i>Instructor, Diesel Engine Department, U S Navy Submarine Department</i>	21	0
ENGINEERING EDUCATOR, PITMAN'S. Edited by W. J. Kearton, M Eng, A M I Mech.E., A M Inst N A. In three volumes	63	0
FRICTION CLUTCHES By R Waring-Brown, A.M.I A E, F R S A, M I P E.	5	0
FUEL ECONOMY IN STEAM PLANTS. By A Grounds, B Sc, A I C., A M I Min E.	5	0
FUEL OILS AND THEIR APPLICATIONS. By H. V Mitchell, F C S.	5	0
MECHANICAL ENGINEERING DETAIL TABLES By John P Ross	7	6
MECHANICAL ENGINEERS' POCKET BOOK, WHITTAKER'S Third Edition, entirely rewritten and edited by W E Dommett, A F Ae S., A M I A E.	12	6
MECHANICS' AND DRAUGHTSMEN'S POCKET BOOK By W. E. Dommett, Wh Ex, A M I A E.	2	6
MECHANICS FOR ENGINEERING STUDENTS. By G W Bird, B.Sc, A M I Mech.E.	5	0
MOLLIER STEAM TABLES AND DIAGRAMS, THE Extended to the Critical Pressure. English Edition adapted and amplified from the Third German Edition by H. Moss, D.Sc, A.R.C.S., D.I.C.	7	6
MOLLIER STEAM DIAGRAMS. Separately in envelope	2	0

Mechanical Engineering—contd.

	<i>s.</i>	<i>d.</i>
MOTIVE POWER ENGINEERING For Students of Mining and Mechanical Engineering By Henry C Harris, B Sc	10	6
STEAM CONDENSING PLANT By John Evans, M Eng, A M I Mech E	7	6
STEAM PLANT, THE CARE AND MAINTENANCE OF A Practical Manual for Steam Plant Engineers By J E Braham, B Sc, A C G I	5	0
STEAM TURBINE THEORY AND PRACTICE By W J Kearton, A M I M E Second Edition	15	0
STRENGTH OF MATERIALS By F V Warnock, Ph D, B Sc. (Lond), F.R.C.Sc.I., A M I Mech E	12	6
THEORY OF MACHINES By Louis Toft, M Sc Tech, and A T J Kersey, B Sc	12	6
THERMODYNAMICS, APPLIED. By Prof W. Robinson, M E, M Inst C E	18	0
TURBO-BLOWERS AND COMPRESSORS By W. J Kearton, A M I M E	21	0
WORKSHOP PRACTICE Edited by E A Atkins, M I Mech E, M I.W.E. In eight volumes	6	0

AERONAUTICS, ETC.

AEROBATICS By Major O Stewart, M C A F C	5	0
AERONAUTICS, DEFINITIONS AND FORMULAE FOR STUDENTS By J D Frier, A R C Sc, D I C	-	6
AERONAUTICS, ELEMENTARY; OR, THE SCIENCE AND PRACTICE OF AERIAL MACHINES By A P Thurston, D Sc Second Edition	8	6
AEROPLANE DESIGN AND CONSTRUCTION, ELEMENTARY PRINCIPLES OF By A W. Judge, A R C S, Wh Ex, A M I A E	7	6
AEROPLANE STRUCTURAL DESIGN By T H Jones, B Sc, A M I E E, and J D Frier, A R C Sc, D I C	21	0
AIRCRAFT, MODERN By Major V W Pagé, Air Corps Reserve, U S A	21	0
"AIRMEN OR NOAHS" FAIR PLAY FOR OUR AIRMEN By Rear-Admiral Murray F Sueter, C B, R N, M P	25	0
AIRSHIP, THE RIGID By E H Lewitt, B Sc, M I A e E	30	0
AVIATION. FROM THE GROUND UP By Lieut G B Manly	15	0
LEARNING TO FLY By F A. Swoffer, M B E With a Foreword by Air Vice-Marshal Sir Sefton Brancker, K C B, A F C	7	6
PARACHUTES FOR AIRMEN By Charles Dixon	7	6
PILOT'S "A" LICENCE Compiled by John F Leeming, <i>Royal Aero Club Observer for Pilot's Certificates</i> Thrd Edition	3	6

MARINE ENGINEERING

MARINE ENGINEERING, DEFINITIONS AND FORMULAE FOR STUDENTS By E Wood, B Sc	-	6
MARINE SCREW PROPELLERS, DETAIL DESIGN OF. By Douglas H Jackson, M I Mar.E, A M I N A	6	0

MOTOR ENGINEERING

	s	d
AUTOMOBILE AND AIRCRAFT ENGINES By A W Judge, A R C S, A M I A E. Second Edition	30	0
CARBURETTOR HANDBOOK, THE By E. W. Knott, A M I A E	10	6
COIL IGNITION FOR MOTOR-CARS By C. Sylvester, A M I E E, A M I Mech E.	10	6
GAS AND OIL ENGINE OPERATION. By J Okill, M I A E	5	0
GAS ENGINE TROUBLES AND INSTALLATION, WITH TROUBLE CHART By John B Rathbun, M E	2	6
GAS, OIL, AND PETROL ENGINES By A Garrard, Wh E	6	0
MAGNETO AND ELECTRIC IGNITION By W Hibbert, A M I E E	3	6
MOTOR TRUCK AND AUTOMOBILE MOTORS AND MECHANISM By T H Russell, A M, M E, with numerous Revisions and Extensions by John Rathbun	2	6
THORNYCROFT, THE BOOK OF THE. By "Auriga"	2	6
MOTOR-CYCLIST'S LIBRARY, THE. Each volume in this series deals with a particular type of motor-cycle from the point of view of the owner-driver	2	0
A J S, THE BOOK OF THE By W C Haycraft Second Edition		
ARIEL, THE BOOK OF THE By G S Davison Second Edition		
B S A, THE BOOK OF THE. By "Waysider" Third Edition		
DOUGLAS, THE BOOK OF THE By E W. Knott Second Edition		
IMPERIAL, BOOK OF THE NEW By F J. Camin		
MOTOR-CYCLING FOR WOMEN By Betty and Nancy Debenham With a Foreword by Major H R Watling		
P AND M, THE BOOK OF THE By W C Haycraft		
RALEIGH HANDBOOK, THE By "Mentor" Second Edition		
ROYAL ENFIELD, THE BOOK OF THE By R E Ryder		
RUDGE, THE BOOK OF THE By L H Cade		
TRIUMPH, THE BOOK OF THE. By E T Brown		
VILLIERS ENGINE, BOOK OF THE By C Grange		
MOTORISTS' LIBRARY, THE. Each volume in this series deals with a particular make of motor-car from the point of view of the owner-driver. The functions of the various parts of the car are described in non-technical language, and driving repairs, legal aspects, insurance, touring, equipment, etc., all receive attention		
AUSTIN TWELVE, THE BOOK OF THE By B Garbutt and R. Twelvetrees. Illustrated by H M Bateman Second Edition	5	0
SINGER JUNIOR, BOOK OF THE By G. S Davison	2	6
STANDARD CAR, THE BOOK OF THE By "Pioneer"	6	0
CLYNO CAR, THE BOOK OF THE By E T Brown	3	6
MOTORIST'S ELECTRICAL GUIDE, THE. By A H Avery, A M I E E.	3	6

OPTICS AND PHOTOGRAPHY

	<i>s</i>	<i>d</i>
AMATEUR CINEMATOGRAPHY. By Capt O Wheeler, F R P S .	6	0
APPLIED OPTICS, INTRODUCTION TO Volume I GENERAL AND PHYSIOLOGICAL. By L C Martin, D Sc, A R C S, D I C	21	0
CAMERA LENSES By A W Lockett	2	6
COLOUR PHOTOGRAPHY By Capt O Wheeler, F R P S	12	6
COMMERCIAL PHOTOGRAPHY By D Charles	5	0
COMPLETE PRESS PHOTOGRAPHER, THE By Bell R Bell	6	0
LENS WORK FOR AMATEURS By H Orford Fourth Edition	3	6
PHOTOGRAPHIC CHEMICALS AND CHEMISTRY By T L J Bentley and J Southworth	3	6
PHOTOGRAPHIC PRINTING By R R Rawkins	3	6
PHOTOGRAPHY AS A BUSINESS By A G Willis	5	0
PHOTOGRAPHY THEORY AND PRACTICE Edited by G. E. Brown	35	0
RETOUCHING AND FINISHING FOR PHOTOGRAPHERS By J S Adamson	4	0
STUDIO PORTRAIT LIGHTING By H Lambert, F R P S	15	0

ASTRONOMY

ASTRONOMY FOR EVERYBODY By Professor Simon Newcomb, LL D With an Introduction by Sir Robert Ball	5	0
ASTRONOMY, PICTORIAL By G F Chambers, F R A S	2	6
GREAT ASTRONOMERS By Sir Robert Ball, D Sc, LL D, F R S	5	0
HIGH HEAVENS, IN THE By Sir Robert Ball	5	0
ROTATION OF THE EARTH, PLANETS, ETC, THE CAUSE OF THE. By Samuel Shields	10	6
STARRY REALMS, IN By Sir Robert Ball, D Sc, LL D, F R S	5	0

ILLUMINATING ENGINEERING

MODERN ILLUMINANTS AND ILLUMINATING ENGINEERING By Leon Gaster and J S Dow Second Edition, Revised and Enlarged	25	0
ELECTRIC LIGHTING IN FACTORIES AND WORKSHOPS By Leon Gaster and J S. Dow	-	6
ELECTRIC LIGHTING IN THE HOME By Leon Gaster	-	6

ELECTRICAL ENGINEERING, ETC.

ACCUMULATOR CHARGING, MAINTENANCE, AND REPAIR By W S Ibbetson, Second Edition	3	6
ALTERNATING CURRENT BRIDGE METHODS OF ELECTRICAL MEASUREMENT By B Hague, D Sc Second Edition	15	0
ALTERNATING CURRENT CIRCUIT By Philip Kemp, M I E E	2	6
ALTERNATING CURRENT MACHINERY, PAPERS ON THE DESIGN OF By C C Hawkins, M A, M I E E, S P Smith, D Sc, M I E E and S Neville, B Sc	21	0
ALTERNATING CURRENT POWER MEASUREMENT By G F Tagg	3	6

Electrical Engineering—contd.

ALTERNATING CURRENT WORK By W Perren Maycock, M I E E Second Edition	s	d
ALTERNATING CURRENTS, THE THEORY AND PRACTICE OF By A T Dover, M I E E Second Edition	10	6
ARMATURE WINDING, PRACTICAL DIRECT CURRENT By L Wollison	18	0
CABLES, HIGH VOLTAGE By P Dunsheath, O B E, M A, B Sc M I E E	7	6
CONTINUOUS CURRENT DYNAMO DESIGN, ELEMENTARY PRIN- CIPLES OF By H M Hobart, M I C E, M I M E, M A I E E	10	6
CONTINUOUS CURRENT MOTORS AND CONTROL APPARATUS By W Perren Maycock, M I E E	7	6
DEFINITIONS AND FORMULAE FOR STUDENTS—ELECTRICAL By P Kemp, M Sc, M I E E	-	6
DEFINITIONS AND FORMULAE FOR STUDENTS—ELECTRICAL IN- STALLATION WORK By F Peake Sexton, A R C S, A M I E E	-	6
DIRECT CURRENT DYNAMO AND MOTOR FAULTS By R M Archer	7	6
DIRECT CURRENT ELECTRICAL ENGINEERING, ELEMENTS OF By H. F. Trewman, M A, and C E Condliffe, B Sc	5	0
DIRECT CURRENT ELECTRICAL ENGINEERING, PRINCIPLES OF By James R. Barr, A M I E E	15	0
DIRECT CURRENT MACHINES, PERFORMANCE AND DESIGN OF By A. E. Clayton, D Sc, M I E E	16	0
DYNAMO, THE ITS THEORY, DESIGN, AND MANUFACTURE By C C Hawkins, M A., M I E E. In three volumes Sixth Edition—		
Volume I	21	0
" II	15	0
" III	30	0
DYNAMO, HOW TO MANAGE THE By A E Bottone Sixth Edition, Revised and Enlarged	2	0
ELECTRIC AND MAGNETIC CIRCUITS—ALTERNATING AND DIRECT CURRENT, THE By E N. Pink, B Sc., A M I E E	3	6
ELECTRIC BELLS AND ALL ABOUT THEM By S R Bottone Eighth Edition, thoroughly revised by C Sylvester, A. M. I. E. E.	3	6
ELECTRIC CIRCUIT THEORY AND CALCULATIONS By W Perren Maycock, M I E E Third Edition, Revised by Philip Kemp, M. Sc., M. I. E. E., A A I E E	10	6
ELECTRIC LIGHT FITTING, PRACTICAL By F C Allsop. Tenth Edition, Revised and Enlarged	7	6
ELECTRIC LIGHTING AND POWER DISTRIBUTION By W Perren Maycock, M I E E. Ninth Edition, thoroughly Revised and Enlarged—		
Volume I	10	6
" II	10	6
ELECTRIC MACHINES, THEORY AND DESIGN OF By F. Creedy, M. I. E. E., A C G I.	30	0

	<i>s</i>	<i>d.</i>
ELECTRIC MOTORS AND CONTROL SYSTEMS. By A T Dover, M I E E, A Amer I E E	15	0
ELECTRIC MOTORS (DIRECT CURRENT): THEIR THEORY AND CONSTRUCTION By H M Hobart, M I E E, M Inst.C.E., M Amer I E E Third Edition, thoroughly Revised	15	0
ELECTRIC MOTORS (POLYPHASE) THEIR THEORY AND CONSTRUCTION. By H M Hobart, M Inst C E, M I E E, M Amer I E E Third Edition, thoroughly Revised	15	0
ELECTRIC MOTORS FOR CONTINUOUS AND ALTERNATING CURRENTS, A SMALL BOOK ON By W Perren Maycock, M I E E	6	0
ELECTRIC TRACTION By A. T Dover, M I E E, Assoc. Amer. I E E Second Edition	25	0
ELECTRIC TRACTION AND POWER DISTRIBUTION, EXAMPLES IN (<i>In the Press</i>)		
ELECTRIC WIRING DIAGRAMS By W Perren Maycock, M I E E	5	0
ELECTRIC WIRING, FITTINGS, SWITCHES, AND LAMPS By W Perren Maycock, M I E E Sixth Edition. Revised by Philip Kemp, M Sc, M I E E	10	6
ELECTRIC WIRING OF BUILDINGS By F C. Raphael M I E E	10	6
ELECTRIC WIRING TABLES By W Perren Maycock, M I E E, and F C Raphael, M I E E Fifth Edition	3	6
ELECTRICAL CONDENSERS By Philip R Coursey, B Sc, F Inst P, A M I E E	37	6
ELECTRICAL EDUCATOR By Sir Ambrose Fleming, M A, D Sc., FRS In two volumes	63	0
ELECTRICAL ENGINEERING, CLASSIFIED EXAMPLES IN. By S Gordon Monk, B Sc. (Eng), A M I E E In two parts—		
Volume I DIRECT CURRENT	2	6
" II ALTERNATING CURRENT	3	6
ELECTRICAL ENGINEERING, ELEMENTARY By O R Randall, Ph D, B Sc, Wh Ex	5	0
ELECTRICAL ENGINEER'S POCKET BOOK, WHITTAKER'S Originated by Kenelm Edgcumbe, M I E E, A M I C E Sixth Edition. Edited by R E Neale, B Sc (Hons)	10	6
ELECTRICAL INSTRUMENT MAKING FOR AMATEURS By S R Bottone Ninth Edition	6	0
ELECTRICAL INSULATING MATERIALS By A Monkhouse, Junr., M I E E, A M I Mech E	21	0
ELECTRICAL GUIDES, HAWKINS'. Each book in pocket size	5	0
1 ELECTRICITY, MAGNETISM, INDUCTION, EXPERIMENTS, DYNAMOS, ARMATURES, WINDINGS		
2 MANAGEMENT OF DYNAMOS, MOTORS, INSTRUMENTS, TESTING		
3 WIRING AND DISTRIBUTION SYSTEMS, STORAGE BATTERIES		
4. ALTERNATING CURRENTS AND ALTERNATORS		
5. A.C MOTORS, TRANSFORMERS, CONVERTERS, RECTIFIERS		

ELECTRICAL GUIDES—*contd.*

6. A C SYSTEMS, CIRCUIT BREAKERS, MEASURING INSTRUMENTS		
7 A C WIRING, POWER STATIONS, TELEPHONE WORK		
8 TELEGRAPH, WIRELESS, BELLS, LIGHTING		
9 RAILWAYS, MOTION PICTURES, AUTOMOBILES, IGNITION		
10 MODERN APPLICATIONS OF ELECTRICITY	REFERENCE	
INDEX		
ELECTRICAL MACHINES, PRACTICAL TESTING OF	By L Oulton, A M I E E, and N. J Wilson, M I E E	Second Edition 6 0
ELECTRICAL TECHNOLOGY	By H Cotton, M B E, M Sc, A M I E E	12 6
ELECTRICAL TERMS, A DICTIONARY OF	By S R Roget, M A, A M Inst C E, A M I E E	7 6
ELECTRICAL TRANSMISSION AND DISTRIBUTION	Edited by R. O. Kapp, B Sc. In eight volumes Vols I to VII, each Vol. VIII	6 0 3 0
ELECTRICAL WIRING AND CONTRACTING	Edited by H Marryat, M I E E, M I Mech E In seven volumes	6 0
ELECTRO-MOTORS: HOW MADE AND HOW USED.	By S R Bottone. Seventh Edition. Revised by C Sylvester, A M I E E	4 6
ELECTRO-TECHNICS, ELEMENTS OF	By A P Young, O B E, M I E E	5 0
ENGINEERING EDUCATOR, PITMAN'S	Edited by W. J Kearton, M Eng, A M I Mech E, A M Inst N A In three volumes.	63 0
INDUCTION COILS	By G E Bonney Fifth Edition, thoroughly Revised	6 0
INDUCTION COIL, THEORY OF THE	By E Taylor-Jones, D Sc, F Inst P	12 6
INDUCTION MOTOR, THE	By H Vickers, Ph.D, M Eng	21 0
KINEMATOGRAPHY PROJECTION. A GUIDE TO	By Colin H Bennett, F C S, F R P S	10 6
MERCURY-ARC RECTIFIERS AND MERCURY-VAPOUR LAMPS	By Sir Ambrose Fleming, M.A, D Sc, F R S	6 0
OSCILLOGRAPHS	By J. T Irwin, M I E E	7 6
POWER STATION EFFICIENCY CONTROL	By John Bruce, A M I E E	12 6
POWER WIRING DIAGRAMS.	By A T. Dover, M I E E, A Amer I. E. E. Second Edition, Revised	6 0
PRACTICAL PRIMARY CELLS	By A. Mortimer Codd, F Ph S	5 0
RAILWAY ELECTRIFICATION.	By H F Trewman, A M I E E	21 0
STEAM TURBO-ALTERNATORS, THE	By L C Grant, A M I E E	15 0
STORAGE BATTERIES. THEORY, MANUFACTURE, CARE, AND APPLICATION	By M Arendt, E E.	18 0
STORAGE BATTERY PRACTICE	By R Rankin, B Sc, M I E E	7 6
TRANSFORMERS FOR SINGLE AND MULTIPHASE CURRENTS	By Dr Gisbert Kapp, M Inst C E., M I E E. Third Edition, Revised by R. O Kapp, B.Sc.	15 0

TELEGRAPHY, TELEPHONY, AND WIRELESS

	<i>s. d</i>
ALL EUROPE "THREE," THE. By R Balbi, A.M.I.E.E., A.C.G.I.	- 6
AUTOMATIC BRANCH EXCHANGES, PRIVATE By R T A. Dennison	12 6
BAUDÔT PRINTING TELEGRAPH SYSTEM By H W Pendry Second Edition	6 0
CABLE AND WIRELESS COMMUNICATIONS OF THE WORLD, THE By F. J. Brown, C.B., C.B.E., M.A., B.Sc. (Lond.)	7 6
CRYSTAL AND ONE-VALVE CIRCUITS, SUCCESSFUL By J H Watkins	3 6
LOUD SPEAKERS By C M R Balbi, with a Foreword by Pro- fessor G. W. O. Howe, D.Sc., M.I.E.E., A.M.I.E.E., A.C.G.I.	3 6
PHOTOELECTRIC CELLS By Dr N I Campbell and Dorothy Ritchie	15 0
RADIO COMMUNICATION, MODERN By J. Reyner. 2nd Ed.	5 0
TELEGRAPHY By T E Herbert, M.I.E.E. Fifth Edition	20 0
TELEGRAPHY, ELEMENTARY By H W Pendry Second Edition, Revised	7 6
TELEPHONE HANDBOOK AND GUIDE TO THE TELEPHONIC EXCHANGE, PRACTICAL By Joseph Poole, A.M.I.E.E. (Wh.Sc.) Seventh Edition	18 0
TELEPHONY By T E Herbert, M.I.E.E.	18 0
TELEPHONY SIMPLIFIED, AUTOMATIC By C W Brown. A.M.I.E.E., <i>Engineer-in-Chief's Department, G.P.O., London</i>	6 0
TELEPHONY, THE CALL INDICATOR SYSTEM IN AUTOMATIC By A. G. Freestone, <i>of the G.P.O., London</i>	6 0
TELEPHONY, THE DIRECTOR SYSTEM OF AUTOMATIC By W E Hudson, B.Sc. Hons (London), Whit Sch., A.C.G.I.	5 0
TELEVISION TO-DAY AND TO-MORROW By Sydney A Moseley and H J Barton Chapple, Wh.Sc., B.Sc. With a Fore- word by John L Baird	7 6
WIRELESS MANUAL, THE By Capt J Frost Second Edition	5 0
WIRELESS TELEGRAPHY AND TELEPHONY, INTRODUCTION TO By Sir Ambrose Fleming	3 6

**MATHEMATICS AND CALCULATIONS
FOR ENGINEERS**

ALGEBRA, COMMON-SENSE, FOR JUNIORS By F F Potter, M.A., B.Sc., and J. W. Rogers, M.Sc.	3 0
With Answers	3 6
ALGEBRA, TEST PAPERS IN By A E Donkin, M.A.	2 0
With Answers	2 6
With Answers and Points Essential to Answers	3 6
ALTERNATING CURRENTS, ARITHMETIC OF By E H Crapper, M.I.E.E.	4 6
CALCULUS FOR ENGINEERING STUDENTS By John Stoney, B.Sc., A.M.I.Min.E.	3 6

DEFINITIONS AND FORMULAE FOR STUDENTS—PRACTICAL MATHEMATICS By L Toft, M Sc	s. d
ELECTRICAL ENGINEERING, WHITTAKER'S ARITHMETIC OF Third Edition, Revised and Enlarged	- 6
ELECTRICAL MEASURING INSTRUMENTS, COMMERCIAL By R M Archer, B Sc (Lond), A R C Sc, M I E E	3 6
GEOMETRY, ELEMENTS OF PRACTICAL PLANE. By P. W. Scott	10 6
Also in Two Parts	2 6
GEOMETRY, EXERCISES IN BUILDING By Wilfred Chew	1 0
GEOMETRY, TEST PAPERS IN By W E Paterson, M A, B Sc.	1 6
Points Essential to Answers, 1s. In one book	2 0
GRAPHIC STATICS, ELEMENTARY By J. T. Wight, A M I Mech E	3 0
KILOGRAMS INTO AVOIRDUPOIS, TABLE FOR THE CONVERSION of Compiled by Redvers Elder On paper	5 0
LOGARITHMS FOR BEGINNERS. By C. N. Pickworth, Wh Sc Fourth Edition	1 0
LOGARITHMS, FIVE FIGURE, AND TRIGONOMETRICAL FUNCTIONS By W. E. Dommatt, A M I A E, and H C Hird, A F Ae S (Reprinted from <i>Mathematical Tables</i>)	1 6
MATHEMATICAL TABLES. By W. E. Dommatt, A M I A E, and H. C. Hird, A F Ae S	1 0
MATHEMATICS AND DRAWING, PRACTICAL By Dalton Grange With Answers	4 6
MATHEMATICS, ENGINEERING, APPLICATION OF By W. C. Bickley, M Sc.	2 6
MATHEMATICS, EXPERIMENTAL. By G R Vine, B Sc —	3 0
Book I, with Answers	5 0
Book II, with Answers	1 4
MATHEMATICS FOR ENGINEERS, PRELIMINARY By W S Ibbetson, B Sc, A M I E E, M I Mar E	1 4
MATHEMATICS FOR TECHNICAL STUDENTS By G. E. Hall	3 6
MATHEMATICS, INDUSTRIAL (PRELIMINARY), By G W Stringfellow	5 0
With Answers	2 0
MATHEMATICS, INTRODUCTORY By J. E. ROWE, Ph D	2 6
MEASURING AND MANURING LAND, AND THATCHERS' WORK, TABLES FOR By J Cullyer Twentieth Impression.	10 6
MECHANICAL TABLES. By J Foden	3 0
MECHANICAL ENGINEERING DETAIL TABLES By John P. Ross	2 0
METALWORKER'S PRACTICAL CALCULATOR, THE By J Matheson	7 6
METRIC CONVERSION TABLES By W E Dommatt, A M I A E.	2 0
METRIC LENGTHS TO FEET AND INCHES, TABLE FOR THE CONVERSION OF Compiled by Redvers Elder—	1 0
On paper	2 0
On cloth, varnished	2 0
MINING MATHEMATICS (PRELIMINARY). By George W Stringfellow	1 6
With Answers	2 0
QUANTITIES AND QUANTITY TAKING. By W. E. Davis. Sixth Edition	6 0

MISCELLANEOUS TECHNICAL BOOKS 17

Mathematics for Engineers—contd. s. d.

REINFORCED CONCRETE MEMBERS, SIMPLIFIED METHODS OF CALCULATING By W N Twelvetees, M I M E, A M I E E	
Second Edition, Revised and Enlarged	5 0
RUSSIAN WEIGHTS AND MEASURES, WITH THEIR BRITISH AND METRIC EQUIVALENTS, TABLES OF By Redvers Elder	2 6
SLIDE RULE, THE By C N Pickworth, Wh Sc Seventeenth Edition, Revised	3 6
SLIDE RULE. ITS OPERATIONS; AND DIGIT RULES, THE By A Lovat Higgins, A M Inst C E	— 6
STEEL'S TABLES Compiled by Joseph Steel	3 6
TELEGRAPHY AND TELEPHONY, ARITHMETIC OF By T. E Herbert, M I E E, and R G de Wardt	5 0
TEXTILE CALCULATIONS By J H Whitwam, B Sc	25 0
TRIGONOMETRY FOR ENGINEERS, A PRIMER OF By W G Dunkley, B Sc (Hons.)	5 0
TRIGONOMETRY FOR NAVIGATING OFFICERS. By W Percy Winter, B Sc (Hons), Lond	10 6
TRIGONOMETRY, PRACTICAL. By Henry Adams, M I C E., M I M E, F S I Third Edition, Revised and Enlarged	5 0
VENTILATION, PUMPING, AND HAULAGE, MATHEMATICS OF By F. Birks	5 0
WORKSHOP ARITHMETIC, FIRST STEPS IN By H P. Green	1 0

MISCELLANEOUS TECHNICAL BOOKS

BREWING AND MALTING By J Ross Mackenzie, F C S, F R M S Second Edition	8 6
CERAMIC INDUSTRIES POCKET BOOK By A B Searle	8 6
ENGINEERING ECONOMICS By T H Burnham, B Sc (Hons), B Com, A M I Mech E	10 6
ENGINEERING INQUIRIES, DATA FOR By J C Connan, B Sc, A M I E E, O B E	12 6
ESTIMATING By T H Hargrave	7 6
FURNITURE STYLES, THE By H E Binstead. Second Edition	10 6
GLUE AND GELATINE By P I Smith	8 6
LIGHTNING CONDUCTORS AND LIGHTNING GUARDS By Sir Oliver J Lodge, F R S, LL D, D Sc, M I E E	15 0
MUSIC ENGRAVING AND PRINTING By Wm Gamble	21 0
PETROLEUM By Albert Lidgett Third Edition.	5 0
PRECIOUS AND SEMI-PRECIOUS STONES By Michael Weinstein	7 6
PRINTING By H A Maddox	5 0
REFRACTORIES FOR FURNACES, CRUCIBLES, ETC By A B Searle	5 0
REFRIGERATION, MECHANICAL By Hal Williams, M I Mech E, M I E E, M I Struct E	20 0
SEED TESTING. By J Stewart Remington	10 6

PITMAN'S TECHNICAL PRIMERS

s. d.

Each in foolscap 8vo, cloth, about 120 pp., illustrated . . . 2 6

In each book of the series the fundamental principles of some subdivision of technology are treated in a practical manner, providing the student with a handy survey of the particular branch of technology with which he is concerned. They should prove invaluable to the busy practical man who has not the time for more elaborate treatises

ABRASIVE MATERIALS By A B Searle

A C PROTECTIVE SYSTEMS AND GEARS By J Henderson, B Sc, M C, and C W Marshall, B Sc, A M I E E

BELTS FOR POWER TRANSMISSION By W G. Dunkley, B Sc. (Hons)

BOILER INSPECTION AND MAINTENANCE By R Clayton

CAPSTAN AND AUTOMATIC LATHES By Philip Gates

CENTRAL STATIONS, MODERN. By C W. Marshall, B Sc., A M I E E

COAL CUTTING MACHINERY, LONGWALL By G F. F Eagar, M I Min E

CONTINUOUS CURRENT ARMATURE WINDING By F M. Denton, A C G I, A Amer. I E E

CONTINUOUS CURRENT MACHINES, THE TESTING OF. By Charles F. Smith, D Sc, M I E E, A M I C E

COTTON SPINNING MACHINERY AND ITS USES. By Wm Scott Taggart, M. I Mech E.

DIESEL ENGINE. THE. By A Orton

DROP FORGING AND DROP STAMPING. By H Hayes

ELECTRIC CABLES. By F W. Main, A M I E E

ELECTRIC CRANES AND HAULING MACHINES By F E Chilton, A M I E E.

ELECTRIC FURNACE, THE. By Frank J Moffett, B.A., M. I. E E., M Cons E.

ELECTRIC MOTORS, SMALL By E T. Pantton, B Sc., A M I E E.

ELECTRIC POWER SYSTEMS. By Capt W T Taylor, M Inst C E., M I. Mech. E

ELECTRICAL INSULATION. By W S Flight, A M I E E

ELECTRICAL TRANSMISSION OF ENERGY By W M. Thornton, O B E, D Sc, M I E E

ELECTRICITY IN AGRICULTURE By A H Allen, M I E E

ELECTRICITY IN STEEL WORKS By Wm McFarlane, B Sc

ELECTRIFICATION OF RAILWAYS, THE By H. F Trewman, M A.

ELECTRO-DEPOSITION OF COPPER, THE. And Its Industrial Applications By Claude W Denny, A M I E E

EXPLOSIVES, MANUFACTURE AND USES OF By R C Farmer, O. B E, D. Sc, Ph D.

FILTRATION. By T. R Wollaston, M. I. Mech E.

FOUNDRYWORK. By Ben Shaw and James Edgar

GRINDING MACHINES AND THEIR USES. By Thos R Shaw, M I Mech E.

HOUSE DECORATIONS AND REPAIRS. By Wm. Prebble.

- PITMAN'S TECHNICAL PRIMERS—*contd.*
- HYDRO-ELECTRIC DEVELOPMENT By J W Meares, F.R.A.S.,
M Inst C.E., M I.E.E., M Am I.E.E.
- ILLUMINATING ENGINEERING, THE ELEMENTS OF. By A. P.
Trotter, M I.E.E.
- INDUSTRIAL AND POWER ALCOHOL By R. C Farmer, O.B.E.,
D.Sc., Ph.D., F.I.C.
- INDUSTRIAL ELECTRIC HEATING By J. W Beauchamp,
M I.E.E.
- INDUSTRIAL MOTOR CONTROL. By A T Dover, M I.E.E.
- INDUSTRIAL NITROGEN By P. H S. Kempton, B.Sc. (Hons.),
A.R.C.Sc.
- KINEMATOGRAPH STUDIO TECHNIQUE By L. C Macbean.
- LUBRICANTS AND LUBRICATION. By J H Hyde
- MECHANICAL HANDLING OF GOODS, THE. By C H Woodfield,
M.I.Mech.E.
- MECHANICAL STOKING. By D. Brownlie, B.Sc., A.M.I.M.E.
(Double volume, price 5s net.)
- METALLURGY OF IRON AND STEEL Based on Notes by Sir
Robert Hadfield
- MUNICIPAL ENGINEERING By H Percy Boulnois, M.Inst.C.E.,
F.R.San.Inst., F.Inst.S.E.
- OILS, PIGMENTS, PAINTS, AND VARNISHES. By R. H. Truelove.
- PATTERNMAKING By Ben Shaw and James Edgar.
- PETROL CARS AND LORRIES By F Heap.
- PHOTOGRAPHIC TECHNIQUE. By L. J. Hibbert, F.R.P.S.
- PNEUMATIC CONVEYING By E G Phillips, M I.E.E.,
A.M.I.Mech.E.
- POWER FACTOR CORRECTION. By A. E. Clayton, B.Sc. (Eng.)
Lond., A.K.C., A.M.I.E.E.
- RADIOACTIVITY AND RADIOACTIVE SUBSTANCES By J.
Chadwick, M.Sc.
- RAILWAY SIGNALLING. AUTOMATIC By F Raynar Wilson.
- RAILWAY SIGNALLING: MECHANICAL By F Raynar Wilson.
- SEWERS AND SEWERAGE. By H Gilbert Whyatt, M.I.C.E.
- SPARKING PLUGS By A. P. Young and H Warren
- STEAM ENGINE VALVES AND VALVE GEARS By E L Ahrons,
M.I.Mech.E., M.I.Loco.E.
- STEAM LOCOMOTIVE, THE By E L Ahrons, M.I.Mech.E.,
M.I.Loco.E.
- STEAM LOCOMOTIVE CONSTRUCTION AND MAINTENANCE By E.
L Ahrons, M.I.Mech.E., M.I.Loco.E.
- STEELS, SPECIAL Based on Notes by Sir Robert Hadfield,
Bart.; compiled by H. T. Burnham, B.Sc. (Double volume,
price 5s)
- STEELWORK, STRUCTURAL By Wm H. Black
- STREETS, ROADS, AND PAVEMENTS. By H Gilbert Whyatt,
M Inst C.E., M.R.San.I.
- SWITCHBOARDS, HIGH TENSION. By Henry E. Poole, B.Sc.
(Hons.), Lond., A.C.G.I., A.M.I.E.E.

- PITMAN'S TECHNICAL PRIMERS—*contd.* s. d.
2 6
- SWITCHGEAR, HIGH TENSION By Henry E Poole, B Sc (Hons),
A C G I, A M I E E.
- SWITCHING AND SWITCHGEAR By Henry E Poole, B Sc (Hons.),
A C G I, A M I E E
- TELEPHONES, AUTOMATIC By F A. Ellison, B Sc, A M I E E.
(Double volume, price 5s)
- TIDAL POWER By A M A Struben, O B E, A M Inst C E
- TOOL AND MACHINE SETTING For Milling, Drilling, Tapping,
Boring, Grinding, and Press Work By Philip Gates
- TOWN GAS MANUFACTURE By Ralph Staley, M C
- TRACTION MOTOR CONTROL By A T Dover, M I E E.
- TRANSFORMERS AND ALTERNATING CURRENT MACHINES, THE
TESTING OF. By Charles F. Smith, D Sc, A M Inst C.E.,
Wh Sc
- TRANSFORMERS, HIGH VOLTAGE POWER By Wm T Taylor,
M Inst C E, M I E E
- TRANSFORMERS, SMALL SINGLE-PHASE By Edgar T Painton,
B Sc. Eng (Hons) Lond, A M I E E
- WATER POWER ENGINEERING By F F Fergusson,
A M Inst C E.
- WIRELESS TELEGRAPHY, CONTINUOUS WAVE. By B E G.
Mittell, A M I E E
- WIRELESS TELEGRAPHY, DIRECTIVE Direction and Position
Finding, etc By L H Walter, M A (Cantab), A M I E E.
- X-RAYS, INDUSTRIAL APPLICATION OF By P H. S Kempton.
B Sc (Hons).

COMMON COMMODITIES AND INDUSTRIES SERIES

- Each book is crown 8vo, cloth, with many illustrations, etc. 3 0
- In each of the handbooks in this series a particular product
or industry is treated by an expert writer and practical man
of business.
- ACIDS, ALKALIS, AND SALTS By G H J Adlam, M A, B Sc.,
F C S
- ALCOHOL IN COMMERCE AND INDUSTRY By C Simmonds,
O B E, B.Sc, F I C, F.C.S.
- ALUMINIUM Its Manufacture, Manipulation, and Marketing.
By George Mortimer, M Inst Met.
- ANTHRACITE By A Leonard Summers
- ASBESTOS. By A. Leonard Summers
- BOOKBINDING CRAFT AND INDUSTRY, THE By T Harrison
- BOOKS: FROM THE MS TO THE BOOKSELLER By J. L Young.
- BOOT AND SHOE INDUSTRY, THE By J S Harding
- BREAD AND BREAD BAKING. By John Stewart.
- BRUSHMAKER. THE. By Wm Kiddier.

COMMON COMMODITIES SERIES—contd. 21

COMMON COMMODITIES AND INDUSTRIES SERIES— <i>contd</i>	s d 3 0
BUTTER AND CHEESE By C W Walker Tisdale, FCS, and Jean Jones, B D F D, N D D	
BUTTON INDUSTRY, THE By W Unite Jones	
CARPETS. By Reginald S Brinton	
CLAYS AND CLAY PRODUCTS By Alfred B Searle.	
CLOCKS AND WATCHES By G. L. Overton	
CLOTHS AND THE CLOTH TRADE By J A Hunter.	
CLOTHING INDUSTRY, THE By B W Poole	
COAL Its Origin, Method of Working, and Preparation for the Market By Francis H Wilson, M Inst M E	
COAL TAR By A R Warnes, FCS, A I. Mech E	
COFFEE From the Grower to Consumer By B B Keable.	
COLD STORAGE AND ICE MAKING By B H Springett	
CONCRETE AND REINFORCED CONCRETE By W. Noble Twelve- trees, M I M E, A M I E E	
COPPER From the Ore to the Metal By H K Picard, M Inst. of Min and Met.	
CORDAGE AND CORDAGE HEMP AND FIBRES By T Woodhouse and P Kilgour.	
CORN TRADE, THE BRITISH By A Barker	
COTTON From the Raw Material to the Finished Product By R J Peake	
COTTON SPINNING By A S Wade	
CYCLE INDUSTRY, THE By W Grew	
DRUGS IN COMMERCE By J Humphrey, Ph C, F J I	
DYES AND THEIR APPLICATION TO TEXTILE FABRICS By A J. Hall, B Sc, F I C, FCS	
ELECTRIC LAMP INDUSTRY, THE By G Arncliffe Percival.	
ELECTRICITY By R E Neale, B Sc (Hons)	
ENGRAVING By T W Lascelles	
EXPLOSIVES, MODERN By S I Levy, B A, B Sc, F I C.	
FERTILIZERS By H Cave	
FILM INDUSTRY, THE By Davidson Boughey	
FISHING INDUSTRY, THE By W E Gibbs, D Sc	
FURNITURE By H E Binstead Second Edition	
FURS AND THE FUR TRADE By J C Sachs	
GAS AND GAS MAKING By W H Y Webber, C E	
GLASS AND GLASS MANUFACTURE By P Marson, <i>Honours and Medallist in Glass Manufacture</i>	
GLOVES AND THE GLOVE TRADE By B E Ellis	
GOLD By Benjamin White	
GUMS AND RESINS Their Occurrence, Properties, and Uses By Ernest J Parry, B Sc, F I C, FCS	
INCANDESCENT LIGHTING By S I Levy, B A, B Sc, F I C.	
INK By C Ainsworth Mitchell, M A, F I C	
IRON AND STEEL Their Production and Manufacture By C. Hood	
IRONFOUNDING By B Whiteley	
JUTE INDUSTRY, THE By T. Woodhouse and P Kilgour.	

- COMMON COMMODITIES AND INDUSTRIES SERIES—*contd.*
- KNITTED FABRICS By John Chamberlain and James H Quilter.
- LEAD. Including Lead Pigments. By J. A. Smythe, Ph.D., D Sc.
- LEATHER. From the Raw Material to the Finished Product. By K. J. Adcock.
- LINEN From the Field to the Finished Product. By Alfred S. Moore
- LOCKS AND LOCK MAKING By F. J. Butter.
- MATCH INDUSTRY, THE By W. H. Dixon.
- MEAT INDUSTRY, THE By Walter Wood.
- MOTOR INDUSTRY, THE By Horace Wyatt, B A.
- NICKEL By F. B. Howard White, B A
- OIL POWER. By Sidney H. North, A.Inst.P.T.
- OILS Animal, Vegetable, Essential, and Mineral. By C. Ainsworth Mitchell, M A, F I C.
- PAINTS AND VARNISHES. By A S Jennings, F I B D
- PAPER. Its History, Sources, and Production. By Harry A Maddox, *Silver Medalist Papermaking* Second Edition
- PATENT FUELS By J. A. Greene and F. Mollwo Perkin, C B E, Ph D, F.I.C.
- PERFUMERY, RAW MATERIALS OF By E. J. Parry, B Sc, F I C, F C S.
- PHOTOGRAPHY By William Gamble, F R P S
- PLATINUM METALS. By E A Smith, A R S M, M.I.M.M.
- PLAYER PIANO, THE By D Miller Wilson
- POTTERY By C. J. Noke and H J Plant
- RICE. By C E Douglas, M I Mech.E.
- RUBBER Production and Utilization of the Raw Product By H. P. Stevens, M A, Ph D, F.I.C., and W. H. Stevens, A.R.C.Sc., A.I.C. Third Edition
- SALT. By A. F. Calvert, F C S
- SHIPBUILDING AND THE SHIPBUILDING INDUSTRY. By J. Mitchell, M.I.N.A.
- SILK. Its Production and Manufacture By Luther Hooper.
- SILVER By Benjamin White.
- SOAP. Its Composition, Manufacture, and Properties. By William H. Simmons, B Sc (Lond.), F C S.
- SPONGES By E. J. J. Cresswell.
- STARCH AND STARCH PRODUCTS By H. A. Auden, D Sc., F C S.
- STONES AND QUARRIES. By J. Allen Howe, O B.E., B.Sc., M.Inst. Min. and Met.
- STRAW HATS. By H Inwards.
- SUGAR. Cane and Beet. By the late Geo Martineau, C B, and Revised by F. C. Eastick, M.A. Fifth Edition.
- SULPHUR AND THE SULPHUR INDUSTRY. By Harold A. Auden, M Sc., D Sc, F.C.S.
- TALKING MACHINES. By Ogilvie Mitchell
- TEA. From Grower to Consumer. By A. Ibbetson.

COMMON COMMODITIES SERIES—contd. 23

	s.	d.
COMMON COMMODITIES AND INDUSTRIES SERIES— <i>contd</i>	3	0
TELEGRAPHY, TELEPHONY, AND WIRELESS By Joseph Poole, A M I E E		
TEXTILE BLEACHING By Alex. B Steven, B Sc. (Lond.), F I C		
TIMBER From the Forest to Its Use in Commerce. By W. Bullock Second Edition		
TIN AND THE TIN INDUSTRY By A H Munday. Second Edition		
TOBACCO From Grower to Smoker By A. E Tanner		
VELVET AND THE CORDUROY INDUSTRY By J Herbert Cooke.		
WALLPAPER By G Whiteley Ward		
WEAVING. By W P Crankshaw		
WHEAT AND ITS PRODUCTS By Andrew Millar		
WINE AND THE WINE TRADE By André L Simon		
WOOL From the Raw Material to the Finished Product By J A Hunter		
WORSTED INDUSTRY, THE By J Dumville and S Kershaw. Second Edition		
ZINC AND ITS ALLOYS By T E Lones, M.A , LL D , B Sc		

Definitions and Formulae for Students

This series of booklets is intended to provide students with all necessary definitions and formulae in a convenient form

AERONAUTICS By J D Frier, A R C Sc , D I C
APPLIED MECHANICS By E H Lewitt, B Sc , A M I Mech E
BUILDING By T Corkhill, F B I C C , M I Str E
CHEMISTRY By W G CAREY, F I C
COAL MINING. By M D Williams, F G S
ELECTRICAL By Philip Kemp, M.Sc , M I E E
ELECTRICAL INSTALLATION WORK By F Peake Sexton, A R.C.S., A M I E E
HEAT ENGINES By Arnold Rimmer, B Eng
LIGHT AND SOUND By P K Bowes, M A , B Sc
MARINE ENGINEERING By E Wood, B Sc
PRACTICAL MATHEMATICS By Louis Toft, M Sc.

Each about 32 pp Price 6d net.

The following Catalogues will be sent post free on application

**Scientific and Technical, Educational, Commercial, Shorthand,
Foreign Languages, and Art**

PITMAN'S SHORTHAND

INVALUABLE TO ALL BUSINESS AND PROFESSIONAL MEN

PITMAN'S
TECHNICAL
DICTIONARY
OF
ENGINEERING AND INDUSTRIAL
SCIENCE
IN SEVEN LANGUAGES
ENGLISH, FRENCH, SPANISH, ITALIAN,
PORTUGUESE, RUSSIAN, AND GERMAN

Edited by

ERNEST SLATER, M.I.E.E., M.I.Mech.E.

In Collaboration with Leading Authorities

THE Dictionary is arranged upon the basis of the English version. This means that against every English term will be found the equivalents in the six other languages, together with such annotations as may be necessary to show the exact use of the term in any or all of the languages.

"There is not the slightest doubt that this Dictionary will be the essential and standard book of reference in its sphere. It has been needed for years."—*Electrical Industries*

"The work should be of the greatest value to all who have to deal with specifications, patents, catalogues, etc., for use in foreign trade"—*Bankers' Magazine*.

"The work covers extremely well the ground it sets out to cover, and the inclusion of the Portuguese equivalents will be of real value to those who have occasion to make technical translations for Portugal, Brazil, or Portuguese East Africa."—*Nature*.

Complete in four volumes Crown 4to, buckram gilt, £8 8s. net

SIR ISAAC PITMAN & SONS, LTD., PARKER STREET, KINGSWAY, W C 2

